STRUCTURAL LANDSLIDE MITIGATION TECHNIQUE

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mior Nazif B Mior Zahari

ABSTRACT

Landslide occurs in most part of the world. It exists in underwater or on land. The effects of one of this Mother Nature can be disastrous and claiming many lives and not to mention the cost for the infrastructure that are destroyed.

These phenomena can be either happens at the non-earthquake area and vice versa. Most contribution to this situation is the excessive pore water pressure and climate change. Pore water pressure can make the soil interaction become weak hence reducing the shear strength of the soil. Once it weak, only matters of time the landslide would occur. Climate change can affect the landslide area by rain, snow, or heat.

In many areas, landslides have different type and shape. Ranging from the material, it carried until to the suitable mitigation. Mitigation can be consists of structure, drainage or internal slope reinforcement application depending on the area. Some area of landslides might have two or more mitigation option depending on the area, cost, and the purpose of the prevention.

Some of the mitigation structures are use to provide facility in certain cases. Applicability on the specific type of landslides is based on the literature review made by the author from various kinds of cases from different kind of journals that are related to the author research topic. Later, the various mitigation is then compiled with its respective landslide failure. The compilations are then used as a reference for the future mitigation measures so that effective measures and prevention can be carried out. As for the recommendation, the author suggests that more detailed study on this topic should be done to make it more effective and useful in the future for the landslide mitigation option. For the conclusion, the author manages to compile and tabulate different type of landslides into its respective mitigation.

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INTRODUCTION TO LANDSLIDE

1.1 Background study

Definitions of landslides are rock, earth, or debris flows on slope due to gravity. Occurring can be due to on any terrain given any right condition of soil, moisture, and angle of slope. Triggering factors can be due to rains, floods, earthquakes and other natural causes as well as human-made causes such as grading, terrain cutting, filling, excessive development etc. Because the factors affecting landslides can be geophysical or human made, the occurrence can be at developed or undeveloped area, or any area where the terrain was altered for roads, houses, utilities, and even for lawn in one's backyard. In USGS and US Department of the Interior (July 2004), factor that contribute to this disaster are be listed as below

Geological causes

a) weak or sensitive material
b) weathered materials
c) sheared, jointed or fissured materials
d) adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact and so forth)
e) contrast in permeability and/or stiffness of materials

Morphological causes

a) tectonic or volcanic uplift
b) glacial rebound
c) fluvial, wave or glacial erosion of slope toe or lateral margins
d) subterranean erosion (solution, piping)
e) deposition loading slope or its crest
f) vegetation removal (fire, drought)
g) thawing

h) freeze or thaw weathering

i) shrink and swell weathering

Human causes

a) excavation of slope or its toe

b) loading at the crest or at slope

c) drawdown (of reservoirs)

d) deforestation

e) irrigation

f) mining

g) artificial vibration

h) water leakage from utilities

Integral to the natural process of the earth surface geology, landslides serve to redistribute soil and sediments in a process that can be abrupt in collapses or in slow mudflows, debris flows, mudflows, earth failures, slope failures and etc.(USGS Planning Research).Example of landslides are illustrated below

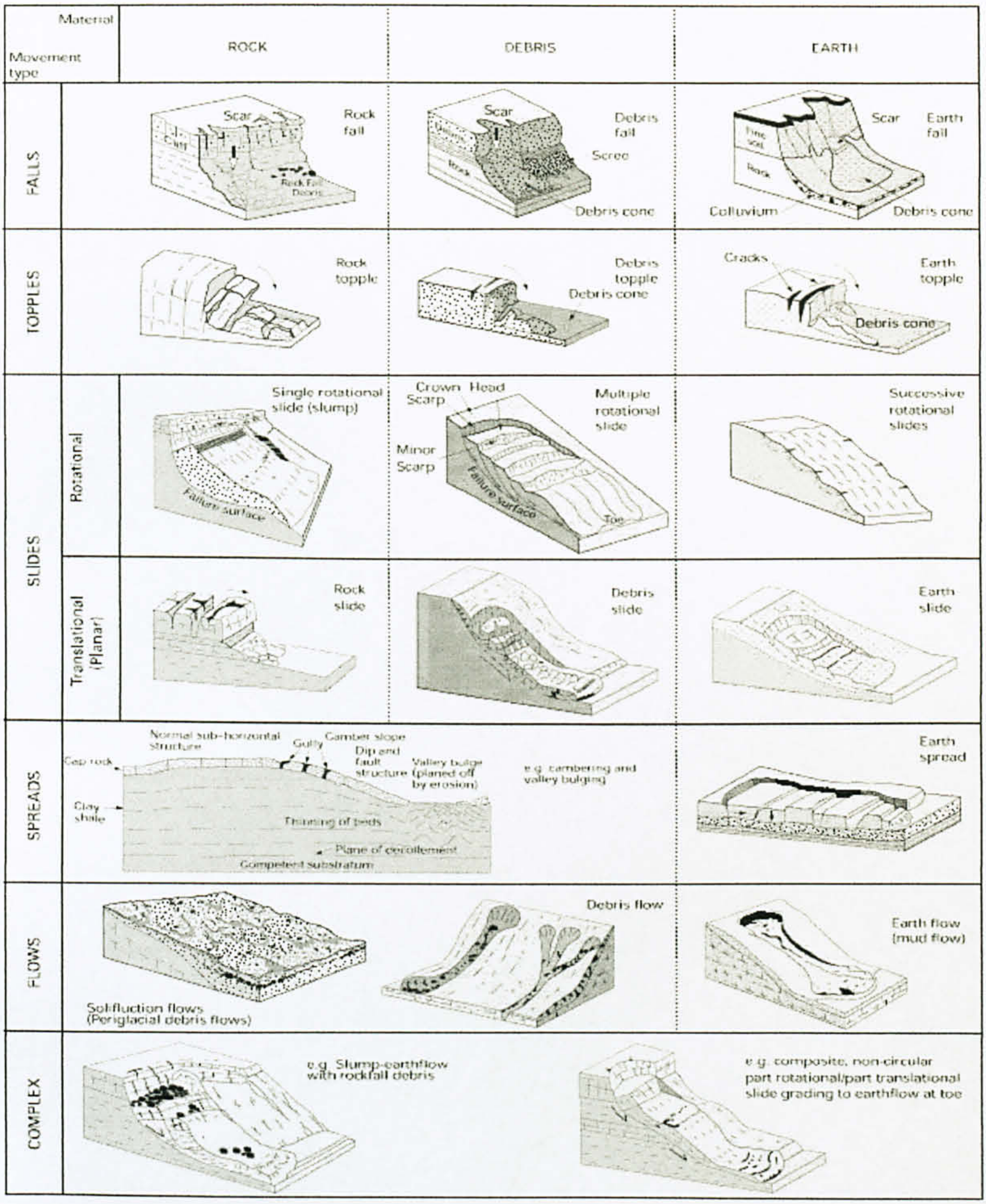

Figure 2 Classification of type of landslip (modified after Varnes, 1978 and DoE., 1990).

Falls mass detached from steep slope/cliff along surface with little or no shear displacement, descends mostly through the air by free fall, bouncing or rolling.
Topples forward rotation about a pivot point.
Rotational slides sliding outwards and downwards on one or more concave-upward failure surfaces.
Translational (planar) slides sliding on a planar failure surface running more-or less parallel to the slope.
Spreads fracturing and lateral extension of coherent rock or soil materials due to liquefaction or plastic flow of subjacent material.
Flows slow to rapid mass movements in saturated materials which advance by viscous flow, usually following initial sliding movement. Some flows may be bounded by basal and marginal shear surfaces but the dominan movement of the displaced mass is by flowage.
Complex slides slides involving two or more of the main movement types in combination.

Other type of landslide form is such as

1. rockfall
2. earthflow
3. creep
4. lateral spread
5. block slide
6. debris avalanche

Three main factors determine the potential for landslides

1. Slope steepness
2. Landform shape
3. Subsurface water

Soil type such as loose and weak soil is more prone to landslides compared to more competent rock or dense firm soils. Competent rock by definition is coherent rock with good bearing strength that is less prone to landslides. Water saturated soils or rock with high water table are much more prone to landslides because the water pore pressure decrease the shear strength of the soil and thus increase the probability of sliding.

Landslides are also can be induced by volcanic activity. This can caused by the melting of the lava, which may melt the snow at rapid rate, causing a deluge of rock, soil, ash, and water that accelerate rapidly on the steep slopes of volcanoes, devastating anything in its path. This volcanic debris flows known as lahars, reach great distances once they leave the flanks of the volcano, and can damage structure in flat area surrounding the volcanoes. The 9180 eruption of Mount St. Helens, Washington triggered a massive landslide on the north flank of the volcano, the largest landslide in recorded time, (United States Geological Science, USGS).

Other definition of landslides variation can be defined as below

1. Rockfalls

- Abrupt movement of masses of geologic material (rock and soils) that become detached from steep slopes or cliffs. Movement can be in bouncing, rolling and free-fall. Falls are strongly induced by gravity, weathering, undercutting, or erosion.

2. Rotational slides

-Rupture surface is curved concavely upwards and the slides movement is rotational about an axis parallel to the slope. Rotational slides usually have a steep scarp at the upslope end and a bulging ‘toe’ of the slid material at the bottom of the slide. Rotational slides may creep slowly or move large distances suddenly.

3. Translational slides

-Moving materials slides along a more or less planar surface. Translational slides occur on surfaces of weaknesses, such as fault or bedding plane or at the contact between firm rock and overlying loose soils. Translational slides might creep slowly or move large distances rather suddenly.

4. Debris flows (debris torrent)

- Surficial movement in which firm soils, rock and organic matter combined with entrain water to form slurries that flow rapidly down slope or within a stream channel. They may travel hundreds to thousands of feet.

Slope failures can range from being a temporary nuisance by partially closing a roadway, to destroying structures, to being catastrophic and even burying cities. This kind of failures occurs in many forms. There is a wide range in their predictability, rapidity of occurrence and movement, and ground area affected, all of which relate directly to the consequence of failure.

Recognition permits the selection of some slope treatment, which will avoid, eliminate, or reduce the hazard. Hazard recognition and successful treatment require thorough understanding of a number of factors including

i. Types and forms of slope failures (classification)
ii. Relationship between geologic conditions and the potential failure form
iii. Significance of slope activity, or amount and rate of movement
iv. Elements of slope stability
v. Characteristics of slope failure forms
vi. Applicability of mathematical analysis

1.2 Problem statement

Each landslide has its own characteristics. Ranging from the shape of the slide until to the material it carried. It also depends on the area that affected by this disaster. Each of the characteristics of the landslide need to be mitigate specifically in terms of functionality and long-term performance.

1.3 Objectives & Scope of study

Focus for this study is to find the suitable structural mitigation measures of landslides for different kind of types. By focusing on the various types of landslides, assessment of slopes and treatment, the author can then differentiate and classify this natural hazards and its prevention based on its degree of suitability.

CHAPTER 2

LITERATURE REVIEW

Mitigation in landslides has various kinds of forms. Ranging from structures to bio engineering methods. By understanding the shape and the type of failure, the engineers can design the suitable mitigation solution. This will affect the cost and the serviceability of the mitigation chosen. Mitigation for example, slope stabilization can be divided in 5 categories such as change of slope geometry to decrease the driving force or increase the resisting forces. Secondly, surface water infiltration control to reduce seepage forces. Thirdly, by control internal seepage to reduce the driving forces and increase material strengths. The fourth is by providing retention to increase the resisting forces. Lastly using injections to increase the strength by applying quicklime slurry into pre-drilled holes has arrested slope movements because of the strength increase from chemical reactions with clays (Handy and Williams, 1976; Broms and Bowman, 1979).

For the selection of the stabilization methods, consideration are given a number of factors including

1. Material types composing the slope, intensity, and orientation of the discontinuities
2. Slope activity
3. Proposed construction; whether cut or side-hill
4. Form and magnitude of potential or recurring failure and remedial measures for the various failures.

For rock falling hazards, it can consists of concrete pedestals for overhangs, rock bolts for jointed masses, bolts and concrete straps for intensely jointed masses, cable anchors o increase support depth, wire mesh to constrain falls, impact walls to deflect or contain rolling blocks, shotcrete to reinforce loose rock with bolts and drains, shotcrete to retard weathering and slaking of shales.

Retaining structures can consists of rock-filled buttress, gabion wall, crib wall, reinforced earth wall, concrete gravity wall, concrete reinforced semi-gravity wall, cantilever wall, counterfort and anchored curtain wall.

For soil nail, the usage has been applied for small slope failures for example in Japan, despite its popularity as one of the slope stabilization techniques. For instance in Japan, the main reason for landslide to occur is due to the abundance of rainfall and the remedy for this are concentrated on groundwater and surface water control as they are the main causes of landslides (Japan Landslide Society and National Conference of Landslide Control, 2002). The use of soil nailing technique in Japan started in 1970's (Japan Highway Public Corporation, 1993, 1995, Express Highway Research Foundation of Japan, 1993). Since then, approximately 50,000 nails have been used every year as temporary earth reinforcement and retaining structures.

In some cases, there are other applications used to prevent landslide such as using pile, (Tia Maria Richardson, PE, Associate Professor, Fairmont State University, August 4, 2005).Base on this journal, the author wrote about how the pile work in case for retaining structure and other parameters that will make a pile as an efficient structure for retention measure. There are two variables that require for design and analysis of a pile, which is

1. driving force from the landslide
2. passive resistance provided by placing the piles

The author also went at suitable site to see the application of this method. The location was badly destroyed by the landslide at Bridgeport, WV Rt 73/73. Besides that, the author also went to three other places to apply the pile retention application and the results were collected.

2.1 Soil Nailing Technology and Japanese Landslide Mitigation Works

Soil nailing is one of the mitigation measures in landslides. This has been applied by Japan in order to find the cost effective solution between ground anchor and soil nail. Besides that, this technique has been only applied for small slope failures. This was written by J Suguwara, Institute Slope Technology Co. Ltd. The paper primarily discussed the two selective method in order to prevent the landslide in Japan which is the ground anchor and soil nailing. Besides that, the author wrote that this technique has been only applied for small slope failures in Japan despite its popularity as one of the slope stabilization techniques in the abstract.

In this paper, the writer told about the related disasters that cause the landslide to occur. Disasters that cause these hazard are due to tectonics activities, heavy seasonal rainfall and due to topographic as well. The writer also obtain the statistical figure, which is number of sediment-related disasters, which comprise of rockfall, landslide and debris flow from 1991 until 2005. Highest statistics was on 2004, which is the rockfall around 1500 sediment-related disasters.

In Japan, the author wrote that the slope movements have been traditionally classified into the following two basic categories which is landslides and rapid slope failures. This was adopted by Watari in 1986. Several criterion such as geology, soil, topography, nature of movement ,rate of movement, warning signs, original gradient, cause triggering mechanism and also the nature of moving mass (blocks).The writer also used landslides measures to classify more deeply on the cases faced in Japan. The landslide control measures and restraint measures are two parameters used in classify the hazards.

For rapid slope failure control and restraint measures, the writer can see several mitigation technique such as drainage, vegetation, shortcreting, pudding, grillage beams, earth removal, retaining walls, anchors (ground anchors and soil nails, etc), piles, rockfall control and hurdle works which based on after Japan River Association, 1997. Moreover, the current design works of soil nailing structures are carried out with the guideline published by Japan Highway Public Corporation (2004). Nails dimension that were used in Japan have the diameter of 19 to 25 mm and the length of 2 to 5 m. The nails are then installed in 65 mm diameter holes and spacing of 1 m to 1.5 m both horizontally and vertically. Angle of installation is generally perpendicular to the slope surface.

Case study was used for comparison between soil nailing and ground anchor usage in the slope stabilization projects in Japan. The case study consists of two different site and they have different kind of landslide cases. Case A which was located in the eastside of Shizouka Prefecture, Japan and there was a road lying about 15 m PD resulting by the earthquake which causing cracks with a significant road subsidence reducing the traffic to one lane. The geology of that site which is 3 m thick fill materials overlying 1.5 m thick layer of Kanto loam which is in turn is underlain by a layer of completely decomposed basalt of approximately 4 m thick. For the calculations, slope stability analysis revealed that 48.6 kN/m of end force was required to enhance the factor of safety of the slips analyzed to 1.15. In economic comparison, total cost for soil nailing was approximately 14 million yen and for ground anchor was about 18 million yen.

Case B location situated in the eastside of Shizouka Prefecture, Japan. Description of the area was a natural slope more than 100 m high and a slope angle of approximately of 65 degree. Deformations occurred at the near portal of the road tunnel existing at the lower part of the slope. Cracks were found due to the stress relief in the mass of geomaterials and basalt as its weathering products. Slope stability were considered separately since its consists of upper and lower part of the slope. For the force description and factor of safety of the slips, the upper part requires 56.3 kN/m of force and 1.15 factor of safety. Lower part requires 42 kN/m of force and factor of safety to be 1.15. Description of the construction with the soil nail are consists of 4 rows of soil nails for the lower part. Specifications are 25 mm diameter and 4 to 5.5 m long, grouted in holes of 65 mm diameter, and placed at a grid of 1.5 x 1.5 m with a declination of 10 degree from the horizontal. Cost was about 22 million yen.

For the ground anchor, the description was two rows of 7.5 to 8.5 m long (anchoring length 3 m) to satisfy the factor of safety of 1.15. Anchors were grouted in holes of 115 mm diameter, and placed at a grid of 2.5 x 2.5 m with a declination angle of 10 degree from the horizontal. Design anchor was 179.3 kN and the total cost was 21 million yen. Reason for the ground anchor selection is due to the stabilizing capacity of the lopes without allowing further deformations in the unstable rock mass.

The author further more discussed in the discussion section by stating that the slope failure occurred in Japan mostly is shallow and 80% of it have their slip surface shallower than 2 m. Limit usage for the soil nail was about 2 to 5 m long and the depth of the slip surface which can be stabilized typically up to 3 m (Japan Highway Public Corporation, 2004). The ground anchor can be implemented if the usage was to stabilize medium to large slope failures even though the substantial bearing arrangements are required at the head. Besides, the ground anchor have prestress which provides active restraint, enabling the anchor to resist service loadings and control displacement. When the required end force to enhance the factor of safety is large, it will reduce the number of drilling holes and this will develop resisting force by applying prestress. Thus, ground anchoring may therefore be more cost effective than the soil nailing particularly when the size of slope failure is relatively large.

2.2 Design of rock fall net fences and the new TAG 027 European guideline

Other mitigation technique used for preventing a landslide is the usage of net fences. The area mostly involved is hilly and steep slope area which consist of different kind of rocks such as igneous and metamorphic rock. The main reason for the failure is due to the weathering agent and erosion, which disintegrate the rock integrity-causing fault which is the break point of the rock fall. Not only the design but also codes of design were also established called the TAG 027 European Guideline.

The writers for this journal, D.Peila and C.Ronco (Department of Land, Environment and Geo-technology, Politechnico di Torino, Turin, Italy) have made a study on using net fences as a rock fall mitigation measures. In the journal, the writers include the speed characteristics of the rock fall which ranges from few meters per second to up to 25-30 m/s (Broili, 1973; Giani, 1992). They also included other researchers devices for rock fall such as ditches, rockfall shelters, ground embankments and net fences made of metallic meshes (Peckover and Kerr, 1977 ; Peila et al., 2007). In the past, there were tests carried out by the manufactures and the universities to defined the maximum energy that can be safely absorbed by net fences (Smith and Duffy , 1990 ; Duffy and Wade ; 1996 ; Gerber 1999 ; Garssel et al., 2003; Peila et al., 2006). Different standards used in the procedure and the results were not easily comparable. Due to this, the

European Organization for technical Approvals (EOTA) has endorsed a new European Technical Approval Guideline (ETAG 027) where testing procedure for CE marking of a net fence (which has been called falling rock protection kit in the guideline) has been defined. The EOTA members also develop a guideline (ETAG) in order to

1. Identify the relevant and regulatory characteristics of the net fences
2. Assessment and verification for the establishments of this method
3. Identify the threshold values that have o be respected for technical reasons
4. Define the identification tests for the kit components

The working group also considered that in Italy, France, and Austria tenders are usually based on the maximum energy that a net fence can sustain, which is measured sing full-scale tests carried out on a prototype, at both inclined and vertical test sites.

EOTA roles are to remove technical obstacles, in the manufacturing sector, for the European falling rock protection kit market through:

- CE marking of the products

- Attestation of conformity of the products

- Determination of the performances of products used in net fence construction by means of technical specifications

- Compliance of trademarks with 6 essential requirements :

1. mechanical resistance and stability
2. safety in the case of fire
3. hygiene, health and environment
4. safety in use
5. protection against noise
6. energy economy and heat retention, which globally define the suitability of use of a product

The parts of net fences consists of interception structure, a support structure and connections components linking them at the end is the foundation which in turn are anchored in the ground. Besides that, they also define the net fences components and its functions and with different kind of protection kit classes depending on the SEL and the MEL value in kJ. MEL and SEL stands for Maximum Energy Level and Service Energy Level respectively. For the MEL requirements, the authors stated that the kinetic energy of an impacting block must fulfills some criteria such as

1. MEL > three times SEL
2. Barrier stops the block during the impacts
3. Block does not touch the ground until the kit reaches the maximum elongation.

For the SEL, the kinetic energy of a block that impacts the kit twice and which allows the following constraints to be fulfilled

- the kit should stop the block during two impacts with the same kinetic energy without maintenance after the first impact
- the block should not touch the ground until the kit reaches maximum elongation during the first and second impacts due to the avoidance of uncontrolled energy dissipation due to ground-block contact and to reduce he energy level absorbed by the barrier
- there will be no ruptures in the connection components after the first impact and the mesh openings should be smaller than twice the initial size of the mesh itself.

For the design of net fences, it is divided into two categories, which is the SEL or MEL approach. There are some criteria that can lead to this two selection which are different fall directions, forecast of low frequency rock fall events and installation position. The first step design is to choose whether to design using SEL or MEL approach

- In the case of a forecast of low frequency rockfall events and with the different fall directions, in other words, not involving the same modulus, it is possible to adopt the MEL approach
- SEL design approach should be taken if the barrier has to be installed in positions in which it is difficult to carry out maintenance work and it is therefore preferable not to repair it after each block impact.

- Both SEL and MEL can be choose if its defined by its alignment design where the same modulus could be impacted several times in the same direction.

For the selection, the authors stated that the designer should verify that

1. The energy that can be dissipated by the net fences is greater than the computed energy of the block.
2. The interception height of the net fence is greater than the interception height
3. Maximum barrier elongation towards the valley multiplied by a safety factor must be smaller than the design distance between the net fence alignment and the area that has to be protected.

The authors also included the flow chart for the design of a rockfall protection device in an area prone to rockfall, which modified from Peila et al., 2006. For the computation of the kinetic energy of the block during the impact is usually carried out using the computed block speed and the design block mass, applying the usual classical physics formulations and the concept of the partial safety factor as indicated in Eurocode7 (point 2.4.7.3.3)

In the conclusion, the authors highlighted the ETAG 027 playing an important role in the design of falling rock protection kits, as it is a credited guideline to test these protection devices. It also makes it possible to compare products based on their absorbable energy level. Other significant information for designers is the maximum elongation of the net fences and the forces applied to the foundations can be obtain during full scale tests for the purpose of design quality improvement. Lastly the data can be combined for a robust design which includes the systematic use of partial safety factors, such as prescribed by the geotechnical Euro code design approach, which represents the official standard in force in Europe for geotechnical work design.

2.3 Simplified pile slope stability analysis.

The used of piles as a retention structures are widely used in the area where slope stabilization are needed. The authors of this journal C.Y Lee, T.S Hull and H.G Poulus present the simplified approach to the study of row piles used for slope stabilization. Theoritical analysis were been used to analyze the slope stability. They stated that the usage of piles to stabilize active landslides is important in slope reinforcement technique. Some of it have been reported by De Beer et al.1970, Ito and Matsui 1975, Sommer 1977, Fukuoka 1977 and Wang et al 1979. The piles used are subjected to lateral force by horizontal movements of the surrounding soil and hence they are considered as passive piles.

They also stated some usage of piles in different country such as Japan used 300 mm diameter steel tube piles to stabilize active landslide area by Taniguchi 1967. Timber piles were used to reinforce slope stability of very soft clays in Sweden while cast in place reinforced concrete piles as large as 1.5 m diameter have been used in Europe and the United States to stabilize active landslides in stiff clays (Bulley 1965 and Offenberger 1981).

In order to analyze the pile, they used conventional Bishop simplified method of slip circle analysis (Bishop 1955) to determine the critical sliding surface, resisting moments, and overturning moments. The pile shear forces and bending moments develop at the sliding surface by the external lateral soil movements are evaluated using a modified boundary element method as described by Hull et al (1991) and employed by Lee et al (1991).

A number of techniques have been developed to evaluate lateral pressure acting piles, which are used as reinforcement in slopes. Reese et al (1992) have presented a "p-y" approach for assessing the improvement in slope stability, which arises from using piles. Rowe and Poulus (1979) developed two dimensional finite element approach that allowed for three dimensional effect of soil flowing through rows of piles. A three dimensional elastic finite element develop by Oakland and Chameau (1984) for the analysis of stabilization of surcharged slope with drilled piles. Some basic failure mechanisms were discussed by Viggiani (1981), Hull et al (1991) and Lee et al (1991).These failure mechanisms provide better insight into the pile-slope stability interaction problem. Ito and Matsui (1975) also incorporated plastic extrusion deformation model to compute lateral pressures acting on a row of passive piles in limit equilibrium solutions for slope stability.

A modified boundary element method (Poulos 1973 ; Hull 1987) which is the alternative approach is to study the response of a row of passive piles incorporated in limit equilibrium solutions of slope stability. The response of the pile-soil maybe modeled as an elastic continuum or a set of springs with uniform variation of stiffness and strength with depth. It incorporates a solution with a nonlinear pile-soil interface element with ability to represent a hardening or softening response prior to reaching an ultimate state. The development of software such as SLOPIL was develop for this analysis. Theoretical solutions have been obtain in order to study the most effective means of using piles for stabilizing slopes.

Method of analysis are divided into slopes stability and pile response and both are considered separately. For pile response, the author elaborate that the failure surface is assumed to be strengthened by the discretely placed piles to form a barrier that resists soil movements and transfers loads to the more stable underlying layers. Large lateral soil movements are subjected in the sliding slope where the portion of the piles embedded. Pile shear forces and bending moments developed at the sliding surface by the external lateral soil movements are evaluated using a modified boundary element method as described by Hull et al. (1991), and employed by Lee et al. (1991).Incremental approach has been develop by analysis with defined soil deformation up to the limiting pile-soil pressure.

The mobilization of pile-soil interface element strengths is the basic requirement that equilibrium must maintained (some elements may remain linear in order to balance he forces and moments produced by the distributed loads). When the piles yield, it is assumed that maximum pile bending moments developed are equal to the yield moments of the piles. Elastic and non-linear effects are incorporated in the analysis for the assumed soil mass by allowing the pile-soil interfaces to yield when they reach specified pile- soil limiting pressures. Interaction effects of identical loaded piles within a group may also be included. Modeling of pile head and base fixities differently are done as well. In clay soil, Young modulus E and pile soil limiting pressure maybe correlated to the undrained shear strength by several multipliers. Solution of pile-soil interaction problem is solved using incremental analysis for increasing lateral soil movements up to and beyond the state at which full pile-soil interface strength has been mobilized.

For the sloe stability section, the authors use the conventional Bishop simplified method to determine the critical sliding surface, resisting moment and overturning moment. The final overall factor of safety of the piled-slope F_{ps} may be determined as follows

$$Fps = \frac{Mrs + Mrp}{Mo} = \frac{Mr}{Mo}$$

Resisting moment generated by the pile is then obtained from the pile shear force and bending moment developed in the pile at the depth of the sliding surface analyzed. Besides that, microcomputer based computer program which is "SLOPIL" has been developed using the uncoupled formulations to analyze the pile-slope stability problem.

In parametric solutions, theoretical solutions have been obtained for a row of hypothetical cast-in place reinforced concrete piles installed in both uniform and two layered soil slope. For the uniform soil slope, the slope is 10 m high and the rigid base at 10 m below the ground surface. Inclination angel of 20 degrees for the slope and assumption were made by using uniform soft clay with undrained shear strength of 30 kN/m^2 and Poisson's ratio of 0.5 plus the density value of 18.5 kN/m^3. Soil Young's modulus and pile soil limiting pressure value are 500 and 9 times the undrained shear strength respectively. Diameter of concrete piles is 1 m and positioned at 3 m center-to-center intervals. Piles are assumed to be positioned between toe and crest of the slope. Pile tips are resting on the rigid base and pile heads plus the tips are free to displace and rotate. Piles are divided into 20 elements and slope is divided into 100 slices across the modeled geometry. Solutions are presented in terms of an improvement ratio, N_{ps} which defined as

$N_{ps}=F_p/F_s$

F_p- factor of safety of pile slope problem

F_s - minimum factor of safety of the slope stability problem without piles

Lastly, the F_s is chosen to be 1 due to the value of the parameters in the problem.

In the homogenous soil slope, the results conclude that the most effective pile positions are near the toe and crest of the slope with piled slope improvement ratio about 1.08. The values become 1.0 when the position is changed close to the middle of the slope, which means that presence of piles has no effect on stability. Reason is the critical sliding surface is near the pile tips. Little influence was found on the stability with the pile heads fixed against rotation since the sliding surfaces in close proximity to the pile heads. Parametric solutions are obtained at the toe (toe piles) and crest (crest piles) which is the most effective of positions of the pile. Increment of piled-slope improvement ratio increased the pile diameter. Larger diameter piles induce larger pile resisting moments and shears and increase the resistance of the slope to failure.

Toe piles appear to be more effective than the crest piles when the pile diameter ratio, d/d_s greater than 1 due to the critical sliding surface is closer to the pile top at the toe piles where larger resisting moments are generated. For the pile spacing, the piled-slope improvement ratio reduces with increasing pile spacing. Resisting moments become smaller with the larger pile spacing, which allows more soil to move through larger clear space between the piles. Contrarily, pile spacing decreases the piles become more like a continuous barrier and the influence of soil arching becomes more pronounced and decreases the soil movements and hence increases the slope stability. The authors also explained the graph where the piled slope improvement ratio increases almost linearly with increasing multiplier, K_{py} (K_{pys}=standard pile-soil limiting pressure multiplier). Larger pile-soil limiting pressure allows the pile to develop larger pile resisting moments and increases the stability since the piles are relatively rigid. As for the conclusion, the author fond that soil modulus and pile stiffness have no or little effect on the pile failure response and in turn on the pile slope stability since the pile failure occurs at the ultimate condition. However, they may influence the pile response prior to failure.

For the other case, which is the two layer soil slope, the piles are embedded into two different soil layer which case A the upper soft layer is underlain by a stiff layer and case B is lower soft layer is overlain by a stiff layer. Pile positions on the piled slope improvement ratio for the pile heads assumed to be free and fixed against rotation. Effective pile positions are between the middle and crest of the slope for case A and case B is at the toe and crest of the slope. In case B, if the locations of piles are at the middle of the slope, the sliding surface intersects near the pile tip resulting no advantage being gained from the piles. In conclusion, pile head fixities have very little effect on the stability of the piled slope for both cases.

The piled-sloped improvement ratio increases almost linearly with the diameter for case A due to most of the critical sliding surfaces intersect along the upper half of the pile where higher pile bending moments and shear forces are developed. For case B, most of the critical sliding surfaces intersect close to the pile tips where lower bending moments and shear forces are developed.

In general, the results confirm the obvious expectation that it is desirable to have the piles embedded through the soft (weak) layers well into the form (stable) underlying layers. The authors stated that the slope stability analysis in this paper considers circular failure surfaces only. In many practical cases, a non-circular surface may be more critical than a circular surface. Extension of the approach presented here in to non-circular failure surfaces is straightforward.

In the conclusions, the authors stated that simplified pile-slope analysis has been discussed which the pile response to lateral soil movements is incorporated in a slope stability analysis. They also investigated some important factors affecting the performance of piles as preventive measures in stable slopes. For homogenous soil slope, piles located at the toe of the slope may provide the most effective slope stabilization. Pile diameter, spacing, and pile soil-limiting pressure are some factor affecting the performance of the stabilizing piles. For a layered soil slope, piles are most effective when they are embedded through the soft layers and extended into the firm or stable layers. Effectiveness of piles is when they are embedded through the soft layers and extended into the firm or stable layers. It also been affected by the pile diameter, spacing and pile soil limiting pressure in a layered soil slope.

2.4 Reinforced ground embankments used for rockfall protection

Rockfall protection structures or barriers can be used in a way to prevent rock fall from rolling down rapidly in the targeted area. It uses energy dissipation where the material itself will absorb the kinetic energy of the rock from falling to rolling on the ground. The most prone area to this phenomenon is the hilly mountainside where very steep slope or overhanging lump of rock that had been weathered for a long time. The main objective for this journal is to analyze the rockfall based on full scale tests on embankments, numerical modeling and also established design guidelines for the embankment. Besides that the authors also have tabulated embankment types and their constructive characteristics. In the full scale tests, most of it have been carried out on prototype embankments by the Colorado Department of Transportation (Barret and White, 1991) ; Burroughs et al (1993) ; Protec Engineering (Yoshida, 1999, www.proteng.co.jp); Gifu University (Japan) (www.proteng .co.jp) ; Tissieres (1999) and by the Politecnico Di torino (Italy) (Peila et al, 1999, 2007).

The latter research involved a complete series of tests on embankments made of sand and gravel reinforced with polymeric geogrids using cable device that is able to launch reinforced concrete blocks with a variable mass and a speed (measured at the impact time) of about 30 m/s and which also used to study net fences (Peila et al, 1998; Peila and Oggeri, 2006). As for the result, the data obtain in these tests have been described in more detail (Peila et l, 1999, 2000, 2002, 2007).

They conducted three types of tests, which the first two were reinforced with polymeric mono-oriented geo-grids, while for test 3 it was left unreinforced. The dip of the faces was kept the same on both sides, around 67 degree angle with an upper layer thickness of 0.9 m (the smallest that could be obtained from a technological point of view), in order to test an embankment with the smallest cross-section that can be built. The result for test 1 indicate that the crater on the mountain side face had a maximum depth of 0.6 m and the extrusion of the soil layers on the valley-side was only about 0.17 m. There are no significant deformation was observed outside the area directly affected by the impact. Test 2 the embankment was subjected to three impacts which were repeated in the same position, at an energy of 4500 kJ, until the embankment collapsed. The first and second impacts makes the embankment successfully stopped the block and remained stable in spite of the large displacements of the soil layers that were observed after the second impact. The third impact shows the displacement on the valley side face was very large and did not allow the stability of the stability of the structure to be maintained. For test 3, the unreinforced embankment collapsed due to the rock block due to a longitudinal tension crack that develop in the middle of the upper layer, along the embankment axis, while the displacement on the valley side face, which was uncontrolled by geogrids, triggered the total collapse of the structure.

For the numerical modeling, the results are mainly focused on a back-analysis of full-scale tests and do not provide a general overview of the embankment behavior or design guidelines. The study was conducted using a systematic set of three-dimensional models developed with the ABAQUS/Explicit Finite Element Method code. This software is based on the "central difference method" which take into account the dynamic aspects of the problems due to the consequent large displacements in the structure. The computation is divided into several minor steps and the displacement, speed, and acceleration of each node of the mesh are evaluated and registered at each time step. In this analysis, the soil was considered a homogenous and mono-phase material and the presence of water was neglected. The first series of analysis, conducted using various speeds, is instead useful to understand the effects of lower speed impacts. The kinetic energy of the block, energy dissipated in irreversible strains (plastic strain and friction), acceleration, speed, and displacement of the block and the shape of the deformed embankments were calculated for each simulation.

Numerical results confirmed that layered structure influences the overall behavior of the embankments as only the layers directly involved in the impact exhibit important displacements. Possibility to verify that 80-85 % of the kinetic energy block is used for soil compaction and plasticization of the impact face and therefore the creation of the crater, 15-20% of the kinetic energy dissipation is due to friction between soil layers.

Last percentage which around 15 to 20% with an increase in the impact energy level. It can be explained by the soil plasticization reduction and a consequent increase in layers sliding occurs. These results are in agreement with those obtained by Peila et al. (2007), who developed a numerical back-analysis of the tests in Chapter 2. If both faces of the embankments analyze it, both displacements values grow with the impact energy with a linear trend until the collapse value is reached. These value of displacement correspond to the minimum sliding compaction of the embankment layers involved in the impact and of the layers above are outside the bottom embankment support base. Other conclusion that were the embankment thickness at the impact height should be increased if the block sizes increase with the same energy level in order to maintain a certain safety factor.

Impacts creates a crater on the embankment mountainside face is why the rolling block does not pass the embankment. It is due to the rolling of the block mills the soil, thus dissipating high energy, and the block is stopped. Numerical results also have confirmed that a rolling block is not able to excavate a trench on the mountainside face and pass over the embankment. Critical situation is when a block impacts on the top of the embankment but it is solvable by introducing and adequate embankment height safety factor. In the design guideline, the authors stated that apart from the static analysis of the embankment and the slope (bearing capacity of the foundations, sliding and tilting) and the internal stability of the embankment (tensile and pull-out strength of the reinforcing elements) (British Standard 8006) ,vital check is important to the structure in order to sustain the dynamic impact without launching fragments during the impact. The design also stated that the condition that the embankment should not launch rock fragments towards the valley during impact is always respected when reinforced soil is used due to the small elements that were made by the structure compared to the size of the falling block. The risk of being passed over depends on the rolling speed of the falling block but the block does not usually have enough rotational energy to pass over the embankment after it has affected and the crater has been created since the mountainside face has a dip of about 70 degree. Stability check should involve verifying that the sliding of the soil layers involved in the impact and the plasticization on the mountain-side face with the creation of the crater, do not trigger the global collapse of the embankment

Considered criteria should be

I. The energy that can be sustained by the embankment is greater than the energy of the falling block which linked to the size and speed of the falling block

$E_{design} - E_{embankment} / \gamma ER \leq 0$

II. Interception height (h_i) that is the embankment height minus the upper soil layer, is greater than the height of the computed trajectories of the falling block (h_{design})

$H_{design} - H_i / \gamma h \leq 0$

For the conclusion, the reinforced embankments can be considered a reliable solution because they permit both high energy levels and multiple impacts to be controlled. Beside that, it also leads to a reduction in maintenance activities for low energy impacts. For the full scale test, it shows that larger spaces is require for their construction compared to net fences and also a careful preparation of a stable foundation ground. Soil properties can be assessed by means of the tests usually carried out for road embankments, thus fulfilling the design requirements in terms of compaction, grain size distribution and deformability. This design scheme permits the deformed shape of the reinforced embankment subjected to block impact to be evaluated and its static stability to be estimated. Displacements are obtained by using FEM comparison approach and a very good agreement has been observed. Simplified analytical tool by analyze the work equilibrium analysis to evaluate the crater size on the mountainside face and the layers sliding towards the valley side face.

The reinforced embankments mainly deforms due to the sliding of the impacted layers and the plasticization of the impacted soil on the mountainside face with the creation of a crater. Choice of an embankment can be based on design charts using numerical modeling or proposed analytical approach. Essential elements for a complete design in the selection of the embankments such as embankment drainage attitude with the reference to the surface hydrology and heterogeneity of the adopted soil, local and global stability of the slope where the embankment is built should be considered as well.

2.5 Using geocells as components of rockfall protection embankments

Other alternatives that can be used as the mitigation technique especially in structural option is by using geocells as the components of the rockfall protection embankments. Definition of embankments refers to ground structures that most often reinforced with horizontal inclusions such as geotextiles or geogrids. Reinforcement inclusions are used to steepen he embankment slope that are facing the impact area to prevent boulders from get over the structure. Efficiency of stopping mainly depends on the mass. Dimensioning from 3 up to 20 m, and length up to hundred meters this can be a problem due to the large area especially on mountainous site. Design of rockfall protection embankments requires knowing the mass of the boulder to be stopped, velocity, and its maximal height of flight in the projected building area. First design requirement is stability versus gravity and sometimes it's the only component considered.

The author, S.L Mabert, P. Gotteland and F.Nicot have investigate the behavior of geocells as components of rockfall protection embankments and the test was conducted by using a 260 kg spherical boulder. The design of rockfall protection embankments requires knowing mass of the boulder to be stopped, its velocity, and its maximal height of flight in the projected building area. The first design requirement is stability versus gravity and it is sometimes the only component considered. The impact by a high kinetic energy boulder induces large and irreversible deformations in the embankments. Tissieres (1999) had compared the boulder braking force to the embankment shearing force assuming that during the impact a section of the embankment is displaced as a rigid body. Generally speaking the engineers design the structure by modeling the impact force by an equivalent static surcharge (Jaecklin, 2006). In addition, these experiments were design to provide data for the calibration of a numerical model of geocells filled with coarse materials and developed using the discrete element method (Bertrand et al., 2006).

For rockfall embankments, geocells can be used to build sandwich protection structures. By changing the fill material, it is possible to adapt the mechanical characteristics of the geocell depending on its position in the structure, similarly to what was proposed by Yoshida (1999). Compared with more classical soil-reinforced rockfall protection embankments, the main difference is that deformations and degradations are accepted during the impact. The kinetic energy of the boulder is dissipated in the front and core-cells, with limited influence on the back of the structure. In case of a low energy event, only the front-face geocells will be deformed.

Higher energy impacts will result in front-face geocell degradation and possibly core-cell deformation. The cellular nature of the structure facilitates maintenance work consisting in mesh repair or replacement of damage geocells. The used of geocells thus offers an alternatives for the construction of rockfall protection embankments, at least for energy events up to 10MJ (RiskYdrogeo, 2006)

The response of the geocell was evaluated in terms of the impact force and the force transmitted by the geocell to its base. Effectiveness was evaluated by the minimization of the transmitted forces. The optimum consists of a geocell filled with a coarse granular material that is laterally free to deform. The reason why is because of the particle crushing. Laterally free to deform geocells transmit the lowest force. Nevertheless, the transmitted force-based criterion is not sufficient to evaluate the ability of a geocell to reduce the effort transmitted in the impacted embankment because it does not account for diffusion. New developments area necessary to account for diffusion in the fill material.

Materials used for filling the geocells are coarse or fine granular non-cohesive materials. The former were crushed quarry limestone, 60 to 180 mm in grain size, it is typical for a talus slope, and it is referred to as 'stone'. The rock Young modulus was 57700 MPa and average crushing resistance of stones 100mm in size was 30 kN. The latter consisted of Hostun sand or scrapped tyres. Hostun sand is a well-documented and well-graded sand whose size distribution ranges from 0.08mm to 1 mm with a friction angle of 32.5 degree. The scrapped tyres result from the puncturing of end of life tyres. This material contains 30% by mass of circular pieces 25 mm in diameter and 10 mm in average thickness, the rest having no particular shape. This material was considered both for waste recycling purposes and to take advantage of its particular mechanical characteristics, very different from the properties of more classical granular geomaterials. Sand was used alone or as a mixture containing 30% by mass of tyres. This mixture constitutes a reinforced and lightweight composite material (Zornberg et al., 2004; Gottelang et al., 2005).The average cell weight was 205, 203 and 195 kg for stones, sand and mixture cells respectively.

In the experimental methodology, the cells were subjected to vertical impact by a 260 kg spherical boulder, 54 cm in diameter and made of a steel shell filled with concrete. Hollow cylinder allowed placing a ± 500 g tri-axial piezoelectric accelerometer close to its centre of gravity (Lambert , 2007).Filled cell was placed on a rigid pedestal made of reinforced concrete dimensioning by 0.7 m in height and 1.2 m side square horizontal cross section. It actually deviates from the real conditions because the surface in contact with the rear of the cell is not rigid. Deformation depending on the force transmitted by the cell, modifying in turn the cell response. Considering both the scale of interest (the cell) and the goals of this study a rigid support was considered. Three different test conditions were considered. The four lateral faces of the impacted cell were i) free to deform (FD) (ii) rigidly confined (RC) (iii) confined by the same material by the fill material (MC). Rigid confinement was obtained using three rigid steel square frames. Material surrounding the MC conditions was contained by a wood and steel structure 0.5 m in height and 1.2 m x 1.2 m in horizontal section (whole surface of the pedestal was covered with this confining material and the cell). RC and FD conditions provided asymptotic responses that can be easily compared with results obtained from numerical simulations while the MC conditions provided the most realistic boundary conditions. Systems of the impact boulder have the capability of dropping the boulder up from 7.5 m in height with an impact centred on the cell and without boulder rotation. Evaluation of the response of the cells is mainly based on the force applied by the boulder on the cell and the force transmitted by the cell to its pedestal. The first is the impact force, denoted F_{imp} which is obtained by multiplying the deceleration of the boulder by its mass. Force transmitted by the cell to the pedestal, F_{trans} could be measured directly beneath the cell due to stone were coarse. Three force transducers supporting the rigid pedestal (capacity 500 kN each) laid on the concrete slab at the testing site. The final penetration of the boulder in the cell, P was also measured as the distance covered by the boulder from the beginning of the impact to the stability position. For cells filled with fine materials, this penetration was less than the maximal penetration during the impact. Duration of impact, d_{imp}, was deduced from the boulder's acceleration measurements. Restitution coefficient, which is the ratio between the reflected velocity and the incident velocity, was calculated. Based on the results, the maximum impact force is always reached a few milliseconds before the end of the impact, thus for the highest penetration. The maximum transmitted force immediately follows it.

Results from the experiment in terms of fill material showed the following trends

- Curves of the impact force on fine material cells were rather smooth compared to stone cells, which showed rapid force variations over the whole impact duration. Average amplitude of the force drops after 10 ms in MC and FD conditions was of 30 kN

- FD conditions showed that impact force curves pronounced peak at the beginning of the impact followed by a quasi plateau (stone cell)

- Second peak on the peak force curve for sand cells in FD conditions, at about 42 ms was immediately followed by the maximum of the transmitted force

- Impacts on stone cells lasted linger, transmitted a lower force and led to a higher cell penetration, whatever the boundary conditions. Stones crushing was observed for all the boundary conditions, and was generalized in RC conditions

- In sand cells, impact and transmitted force were lower compared to mixture cells

In boundary conditions specifically

- After 10 ms, the cell responses in terms of impact force were very different depending on the boundary conditions, while the curves very similar before 5 ms
- Restraining the lateral deformation (from FD to RC conditions) led to (i) reduction of both the penetration and the impact duration by a factor of 3 to 4 (ii) increase in both the maximum values of the impact and the transmitted force. Impact force on sand cells appeared to be more sensitive to the boundary conditions than on stone cells. Ratio increment form FD to RC conditions was of 3.8 in the case of sand cells vs 1.7 for stone cells.
- Restraining the lateral deformation (form FD to RC conditions) increased the coefficient of restitution. IN fact, boulder rose again or rebounded with the cells filled with sand or tyre-sand mixtures and also after impacts on stone cells in RC conditions
- Maximum force transmitted by the cells in FD conditions was the lowest, followed by the cells in MC conditions

In conclusion, the results clearly showed that both the boundary conditions and the fill material have a great influence on the cell response. In the statistical form, the transmitted force depends on the boundary conditions and less on the fill material.

It is worth knowing that the transmitted force is most often higher that the impact force. Moreover, the ratio between the two depends on the impacted structure. Various authors (Masuya and Kajikawa, 1991; Monatni Stoffel, 1998; Calvetti, 1998; Calvetti et al, 2005) have observed this phenomenon referred to as dynamic amplification by Calvetti et al.(2005). The ratio ranged from 1.1 to 3. The fill material dissipates energy, mainly by friction and crushing. The tyre-sand mixture is less effective than the sand alone as fill material for all boundary conditions. Considering the differences in the characteristics of these materials (unit weight, peak strength, etc) different behaviours were expected. In fact, the tyre-sand ratio of this mixture was defined based on static tests (Gotteland et al., 2005) and this criterion appears not to be satisfactory for dynamical loadings.

In the discussion, the authors explain that from the beginning of the impact, the kinetic energy of the impacting boulder is progressively transferred to the cell under the form of kinetic energy and strain energy (Masuya and Kajikawa, 1991). After transit through the cell, the energy is transferred to the rigid base as strain energy. However, depending on both the lateral boundary conditions and the fill materials, the response of the cell to this energy transfer will be different.

In an impact on a stone cell, the rapid variation observed on the impact force curves is explained by the coarse nature of the fill material. The cell contains a limited number of "particles" (about 100).The forces transit through force chains (Radjai et al., 1998), involving only a fraction of the particles and forming column patterns. Any particle movement or crushing in these columns causes a sudden drop in the impact force (Tsoungui et al., 1999).Other characteristics that were govern by boundary condition is the ratio of kinetic vs strain energy transferring through the cells filled with fine material. Main difference is that the transfer of energy through the particle assembly causes it to compact (Scott and Pearce, 1975). The cell is composed of two elements: the fill material and the envelope. Cell dynamic response depends on the characteristics of both. Confining effect by the envelope does not play an important role in the case of confined cells (MC and RC conditions) since it requires a large lateral deformation of the cell which is not attained (Lambert, 2007).

Crushing is fundamental phenomenon in the response of stone cells. Stone crushing has two consequences. First, it dissipates energy and limits the impact force to a threshold value which proportional to the crushing resistance of the stones (Lambert, 2007) and to the contact area between the impacting boulder and cell. The impact force equals the sum of the forces transiting through through the force chain in the cell. Higher crushing resistance of the stones, giving higher force transitting through each chain and the larger the contact area, the higher the number of force chains involved. Impact force drops observed on stone cells in MC and FD conditions can be associated with stones crushing. This phenomenon also explains that in RC conditions the slope of the impact force tends to diminish about 10 ms after contact whereas it increases progressively up the the peak in case of sand cell. A fine material progressively compacts with increasing boulder penetration leading to the increase in the impact force by comparison. Influence of sand compaction appears clearly whatever the boundary conditions: the maximum impact force is always reached a few milliseconds before the end of the impact, thus for the highest penetration followed by the maximum transmitted force. Impact force curves thus appear to be highly relevant in understanding the behaviour of the impacted cells and interpreting the transmitted force curves. It also reveals that the dynamics of the energy transfer from the boulder to the cell. Noting that the transmitted force is most often higher than the impact force. Ratio between the two depends on the impacted structure. Authors like (Masuya and Kajikawa, 1991: Montani Stoffel, 1998; Calvetti et al ., 2005) have observed this phenomenon referred ad dynamic amplification and the ratio ranged from 1.1 to 3. Consequently, the impact force alone is definitely not sufficient to estimate the transmitted force. Moreover, the fill material dissipates energy, mainly y friction and crushing. Tyre sand mixture is less effective than sand alone as fill material for all the boundary conditions. The tyre-sand ratio of this mixture as defined based on static tests (Gotteland et al., 2005) and this criterion appears not to be satisfactory for dynamical loading. The boundary conditions have a greater influence on the transmitted force than the tyre of fill material. Optimizing the boundary conditions seems to be a valuable alternative to reduce the transmitted force.

Obviously, a laterally -free- to-deform cell directly subjected to impact does not diffuse the forces in the structure, contrary to a cell in lateral contact with other cells. It is more appropriate to consider stresses rather than forces in this case. In soils, the stresses diffuses within a cone I the material (Calvetti , 1998; Montani Stoffel, 1998; Nomura et al ., 2002).Montani Stoffel observed that the diffusion angle for three layers vary significantly, ranging from 33 to 47 degree and the stress distribution is not uniform. For other fill material, diffusion is more complex. First, the envelope's influence should not be neglected because it may modify the diffusion angle and the stress distribution in soil is not suitable for impacts on stone layers or on tyre sand mixture layers. One can postulate that taking into account diffusion will lead to different conclusions than those drawn from the force-based criterion. Besides, the rigid base is not representative of the boundary conditions at the rear of the cell at the structure scale. The impacted cell is expected to move inwards of the structure, depending on the characteristics of this backing and giving opportunity for other phenomena to take place. Expectation of reduction of impact and an increase of both the impact duration and the boulder penetration the the main work of the REMPARe project.

The authors also stated that the coarse granular fill material geocell appears to be the most effective whatever the boundary of geocells boundary conditions, because of particle crushing. Laterally free to deform geocells transmit the lowest force. Transmitted force based criterion is not sufficient to evaluate the ability of a geocell to reduce the effort transmitted in the impacted embankment because it does not account for diffusion.

2.6 Landslide causal factors and remediatial option

For this journal, the mitigation measure is more general compare to its landslide. The author, M. E. Popescu discussed about the landslide causal factors and remediatial options. The author in his/her journal explain more detail about the cause of the landslide, remedial options, level of effectiveness for each remedial measures, landslide activity and hazard mitigation and lastly the ground investigation, monitoring and back analysis of slope failures to design remedial works.

In the first part, the author cited that the causes of failure are divided into several categories. There are six portions of the causal factors which are ground conditions, geomorphological processes, physical processes and man made process. The detail of ground conditions are plastic weak material, sensitive material, collapsible material, weathered material, sheared material, fissured material, adversely jointed mass discontinuities(including bedding, schistosity, cleavage), adversely oriented structural discontinuities(including faults, unconformities, flexural shears, sedimentary contacts) and contrast in permeability and its effects on groundwater contrast in stiffness (stiff, dense material over plastic material).

For geomorphological factors, there are tectonic and volcanic uplift, glacial rebound, fluvial, wave and glacial erosion of the slope toe, erosion of the lateral margins, subterranean erosion (solution, piping), deposition loading of the slope or its crest and vegetation removal (by erosion, forest fire, drought). Physical processes includes intense and short period rainfall, rapid melt of deep snow, prolonged high precipitation, rapid drawdown following floods, high tides or breaching of natural dams, earthquake, volcanic eruption, breaching of crater lakes, thawing of permafrost, freeze and thaw weathering, shrink and swell weathering of expansive soils.

The last factor which is man-made processes such as excavation of the slope or its toe, loading of the slope or its crest, drawdown (of reservoirs), irrigation, defective maintenance of drainage systems, water leakage from services (water supplies, sewers, storm water drains), vegetation removal (deforestation), mining and quarrying (open pits or underground galleries), creation of dumps of very loose waste, and artificial vibration (including traffic, pile driving, heavy machinery)

In the first part as well, the author also explained the factor of safety from different person such as Terzaghi and Varnes. For Terzaghi, he defined the factor of safety, F, of a slope results from comparing the downslope shear stress with the shear strength of the soil along an assumed or known rupture surface. He divided the landslide causes into external causes with the result of increase of the shearing stress (e.g. geometrical changes, unloading the slope toe, loading the slope crest, shocks and vibrations, changing water regime, drawdown) and internal causes which results in a decrease of the shearing resistance (e.g. progressive failure, seepage erosion, weathering).

For Varnes (1978), the author pointed out that there are a number of external or internal causes, which may be operating either to reduce shearing resistance or to increase the shearing resistance. Related causes affecting simultaneously both terms of the factor of safety ratio exists between these two parameters.

Popescu in 1984 cited that the great variety of slope movements reflects the diversity of conditions that cause the slope to become unstable and the processes that trigger the movement. It is more appropriate to discuss the causal factors (including both "conditions" and "processes") than weak) than "causes" per se alone. The influential criteria such as ground conditions (weak strength, sensitive fabric, degree of weathering and fracturing) are influential criteria but are not causes. They are part of the conditions necessary for unstable slope to develop, to develop, to which must be added the environmental criteria of stress, pore water pressure and temperature. It does not matter if the ground is weak as such – failure will only occur as a result if there is an effective causal process, which acts as well. Such causal processes may be natural or anthropogenic, but effectively change the static ground conditions sufficiently to cause the slope system to fail, i.e. to adversely change the stability state. The author also made a figure in order to facilitate a better understanding of landslide causes, which shows an example of factor of safety. From the figure, it showed that rainfall have a significant effect in landslide. Factor of safety is seasonally varied by reflected of the seasonal rainfall and evaporation. Seasonal variation can be long-term trend in groundwater levels, or changes in strength due to weathering. Sudden changes including the strength of the materials or the forces applied to the slope.

For Varnes in 1978, the author stated that process that lead to the development of the slide has its beginning with the formation of the rock itself, when its basic properties are determined and includes all the subsequent events of crustal movement, erosion, and weathering. Crozier in 1968 said that value of the factor of safety is a clear and simple distinction between stable and unstable slopes. Better visualization for slopes in terms of slope stages such as stable, marginally stable and actively unstable are used from the physical point of view.

The author explained that stable slopes are those where the margin of stability is sufficiently high to withstand all destabilizing forces. Marginally stable slopes are those, which will fail at some time in response to the destabilizing forces attaining a certain level of activity. For actively unstable slopes, the destabilizing forces produce continous or intermittent movement. For the three stability stages, it must be seen to part of a continuum, with the probability of failure being minute at the stable end of the spectrum, but increasing through the marginally stable range to reach certainty in the actively unstable stage. This can be seen by the next diagram which is the probability distribution cruve of the factor of safety for any set of slopes in a specified environment (DOE, 1994). Other figure shows that in any one area, it is likely that more slopes will be subjected to minor forms of mass movement, such as creep, than to large-scale displacements such as deep-seated failures. The three stability stages provide a useful framework for understanding the causal factors of landslides and classifying them into two groups based on their function:

1. Preparatory causal factors, which make the slope susceptible to movement without actually initiating it and thereby tending to place the slope in a marginally stable state.
2. Triggering causal factors, which initiate movement. The causal factors shift the slope from a marginally stable to an actively unstable state.

Particular causal factor may perform either or both functions, depending on ts degree of activity and the margin of stability. Explanation of ultimate causes of a landslide invariably involves a number of preparatory conditions and processes and it may be possible to identify a single triggering process. Destabilizing processes based on temporal variability may be grouped into slow changing (e.g. weathering, erosion) and fast changing processes (e.g. earthquake, drawdown). Processes within the slope system, which provoke the greatest rate of change is given priority in the search of landslide causes. Fast change can be identified as having triggered movement while slow changes act over a long period to reduce the resistance/shear stress ratio. Operational approach to classification of landslide causal factors proposed by the WP/WLI is intended to cover the majority of landslides. Consideration of the available data from simple site investigation and information furnished by other site observations are the two criteria involved.

Landslide causal factor are divided according to their effect (preparatory or triggering) and their origin (ground conditions and geomorphological, physical or man-made processes). Ground conditions may not have a triggering function, while any ground condition or process may have a preparatory function. For ground conditions or the material and mass characteristics of the ground, can be mapped on the surface of the landslide and the surrounding ground and explored in the subsurface by drilling, trenching and edits. Mechanical characteristics can be determined by testing. Changes in geomorphology of the ground, can be documented by pre-existing maps, aerial photographs, surveys of the landslide, or careful observation over time by the local population.

Physical processes concern the environment can be documented at the site by instrumentation such as rainfall gauges, seismographs or piezometers. Acceptable substitute can be for example careful observations over time of water wells or damage from earthquakes. Variations in mechanical properties with the distance from the surface may, in some circumstances, indicate changes of these properties with time. Observation and excavation records at site can be the documentation fro the man made processes. Separate identification of artificial and natural landslides is useful for both administrative and theoretical reasons.

In the next section, which is the comments on landslide remedial measures the author have cited the selective measures for each class of the mitigation measures in the table. The selective measures consists of 4 major part which are modification of slope geometry, drainage, retaining structures and internal slope reinforcement. In this section, the author cited that the prevention of a pending landslide is a function of a reduction in the driving forces or an increase in the available resisting forces. Any remedial measure used must provide one or both of the above results. Many landslide remedial measures from the reader are mostly directed to Hutchinson (1977), Zaruba and Mencl (1982), Schuster and Bromhead (1992) and lastly Fell (1994).

Based on Hutchinson (1977), the author stated that drainage is the principal measure used in the repair of landslides, with modification of slope geometry the second most used method. These are also generally the least costly of the four major categories, which is obviously why they are used the most. For most landslide remedial measures, the option adopted probably more than one for example while restraint may be the principal measure used to correct a particular landslide, drainage and modification of slope geometry, to some degree and necessity, are also utilized. For deep seated slides, the slope geometry modification is the most efficient method but the success of it also depends on the position of the slope as well. Hutchinson (1977) provides details of the "neutral line" method to assist in finding the best location to place a stabilizing fill or cut. There are some situations where this approach is not simple to adopt . This is due to the long transitional landslides where there is no obvious toe or crest; situations where the geometry is determined by engineering constraints; situations where unstable area is and thus a change in topography, which improves of one area many reduce the stability of another.

Bromhead in 1992 stated that drainage is often a crucial remedial measure due to the important role played by pore-water pressure in reducing shear strength. The reason is that the high stabilization efficiency in relation to cost. But the weakness is from the maintenance point of view if it want to be function continuously. Surface water is diverted from unstable slopes by ditches and pipes. Drainage of the shallow groundwater is usually achieved by networks of trench drains. For the failure surface, the drainage is achieved by counterfort or deep drains which are the trenches sunk into the ground to intersect the shear surface and extending below it. For deep landslide, drainage tunnels are driven into the intact material beneath the landslide. From this position, a series of upward-directed drainage holes can be drilled through the roof of the tunnel to drain the sole of the landslide. Alternatively, the tunnels can connect up a series of vertical wells sunk down from the ground surface. In instances where the groundwater is too deep to be reached by ordinary trench drains and where the landslide is too small to justify an expensive drainage tunnel or gallery, bored sub-horizontal drains can be used. Another approach is to use a combination of vertical wells linked to a system of sub-horizontal borehole drains.

Schuster (1992) discusses recent advances in the commonly used drainage systems and briefly mention less common used, but innovative, means of drainage, such as electro-osmotic deatering, vacuum and siphon drains. Buttress counterforts of course-grained materials placed at the toe of unstable slopes often successful due to their hydrological effect and "retaining Structures" for their mechanical effect. When properly design the sophisticated techniques such as passive piles and piers, cast-in-situ reinforced concrete walls and reinforced earth retaining structures it can be extremely valuable especially in areas with high loss potential or in restricted sites. However fixation with structural solutions has in some cases resulted in the adoption of over-expensive measures that proved to be less appropriate than alternative approaches involving slope geometry modification or drainage (DOE, 1994).

Over the last several decades there has been a notable shift towards "soft engineering" non-structural solutions including methods such as lime/cement stabilization, grouting or soil nailing (Powel, 1992). The cost for non-structural remedial measures are less rather than structural measures. Structural solutions involve opening the slope during construction and often require steep temporary cuts. These can increase the risk of failure during construction or over-steeping or increased infiltration from rainfall. Using soil nailing in contrast as a non-structural solution to strengthen the slope avoids the need to open or alter the slope from its current condition. Environmental factor can be an issue for example visual intrusion in scenic areas or the impact on nature or geological conservation interest.

In soft-engineering, the combination of man made structural elements combined with vegetation to stabilize slope is called biotechnical slope stabilization (Schuster, 1992). This vegetative stabilization method works by the processes of interception of rainfall, and transportation of groundwater, thus maintaining drier soils and enabling some reduction in potential peak groundwater pressures. The vegetation roots reinforce the soil, increasing soil shear strength while tree roots may anchor into firm strata, providing support to the upslope soil mantle through buttressing and arching. A small increase in soil cohesion induced by the roots has a major effect on shallow landslides. Mechanical effect of vegetation planting is not significant for deeper-seated landslides while the hydrological effect is beneficial for both shallow and deep landslides. However, vegetation may not always assist in slope stability by the action of surcharge by the vegetation itself and by wind forces on the vegetation exposed, though both these are very minor effects. It also can act adversely by penetrating and dilating the joints of widely jointed rocks. More detail about these can refer to Greenway (1987) and Wu (1991). Additionally, the "Geotechnical Manual for Slopes" (Geotechnical Control Office of Hong Kong, 1981) includes an excellent table noting the hydrological and mechanical effects of vegetation.

Biotechnical slope stabilization is generally cost effective compared to the structural elements alone by increasing the environmental compatibility and allow the use of local natural materials. Interstices of the retaining structure are planted with vegetation whose roots bind together with soil within and behind the structure. Stability from this vegetation are benefited by structures such as retaining structures with open gridwork or tiered facings. Example of a composite vegetated geotextile/geogrid reinforced structure named "Biobund" was presented by Barker (1991).

In the next section part, the author discussed about the levels of effectiveness and acceptability that may be applied in the use of remedial measures. Based on Terzaghi (1950), the stopping movement of a moving slope must be adapted, which started the slide. Example if erosion is a causal process of the slide, the remedial measures are armoring the slope against the erosion or removing the source of erosion. An erosive spring can be made non-erosive by either blanketing with filter materials or drying up the spring with horizontal drains etc.

Benefit gain in understanding landslide-producing processes and mechanisms lies in the use of this understanding to anticipate and devise measures to minimize and prevent major landslides. Major here means that it is neither possible nor feasible, nor even desirable, to prevent all landslides. Landslide avoidance through selective locationing is obviously desired- even required- in many cases, but the dwindling number of safe and desirable construction sites may force more and more the use of landslide-susceptible terrain. Selection of proper remedial measure depends on a) engineering feasibility, b) economic feasibility, c) legal/regulatory conformity, d) social acceptability, and e) environmental acceptability.

Engineering feasibility involves analysis of geologic and hydrologic conditions at the site to ensure physical effectiveness of the remedial measure. An often-overlooked aspect is making sure the design will not merely divert the problem elsewhere. Economic feasibility takes into account the cost of the remedial action to the benefits it provides. These benefits include deferred maintenance, avoidance of damage including loss of life, and other tangible and intangible benefits. Legal-regulatory conformity provides for the measure meeting local building codes, avoiding liability to to other property owners, and related factors. Social acceptability is the degree to which the remedial measure is acceptable to the community and neighbors. Some measures for a property owner may prevent further damage but be an ugly eyesore so neighbors. For the environmental acceptability, the remedial measure is not to adversely affect the environment. De-watering a slope to the extent it no longer supports a unique plant community may not be environmentally acceptable solution. Cases like the permanent closure of the Manchester-Sheffield road at Mam Tor in 1979 (Skemptron et al., 1989) and the decision not to reopen the railway link to Killin following the Glen Ogle rockslide in U.K. (Smith, 1984) are well known examples of abandonment due to the effects of landslides where repair was considered uneconomic.

Landslides actually must be dealt with sooner or later. This depends on the processes that prepared and precipitated the movement, the landslide type, kinds of materials involved, size and location of the landslide, place or things affected by or the situation created as a result of the landslide, available resources etc. The technical solution must be in harmony with the natural system, otherwise the remedial work will be either short-lived or excessively expensive. Since landslides are varied in type and size, and always, so dependent upon special local circumstances, that for a given landslide problem there is more than one method of prevention or correction that can be successfully applied. This success depends on the specific soil and groundwater condition that are correctly recognized in investigation and applied in design.

2.7.1 Stabilization and remediation of a minor landslide affecting the A5 trunk road at Llangollen, North Wales, UK

The author, D. Nicol and R.D.W Lowman had written a mitigation measures and stabilization of minor landslide affecting the A5 trunk road at Llangolen, North Wales, UK. A brief background of this road is that it is the main route from London to Ireland (via Holyhead) and it representing one of the great engineering projects by Thomas Telford during its time.

Geological setting of the area were described by Will and Smith (1922) and Wed et al. (1927). Bedrock at site comprises a monotonous sequence of mudstones and siltstones assigned to the Elwy Group (Ludlow Series) of the Silurian age. Moderately strong to strong, well jointed, thinly laminated dark grey silty mudstones and clayey siltstones predominate and are observationally accessible 100 m to the east of Hafan Deg in the road cutting where they dip at shallow angle southwards. Slopes are mantled by thin drift (superficial) cover, generally less than 2 m, of heterogenous stiff brown and grey till of Pleistocene glacial origin and alluvium of relatively recent age.

The landslide event took place on 7th of December 7, 1994 due to high rainfall intensity due to prolonged summer. The landslide measured 5.85 m at its widest point. Backscar was generally curve in plan and a pattern of tension cracks develops upslope as the landslide progressed by downslope rotational movement. Downslope displacements of about 50-500 mm were observed across the tension cracks.

Site investigation revealed that the strata encountered are soil and subsoil overlying a transitional horizon of weathered rock that gradates downwards into fresh bedrock. The soil and subsoil consists of sandy clay with gravel to cobble-sized fragments of mudstone, siltstone, and sandstone. The underlying weathered rock comprise brown and grey, stiff to very hard materials of variables engineering properties. In its unweathered state, the Silurian bedrock consists predominantly of dark grey, weak to moderately strong mudstone and siltstone. Ground movement involve slipping primarily within the upper soil of the lower portion of the slope as a result of high water pressures above the subsoil layer and rockhead surface, a finding that accords with the prolonged wet weather. The sudden failure and significant displacement suggest that a large volume of water was available to permit mobility of the landslide debris and this is ascribed to the apparent lack of adequate drainage facilities within the slope and the retaining wall.

The remediation options included a mass concrete retaining wall, soil nailing, a mini pile wall, an anchored wall and a reinforced concrete retaining wall. A modified mini pile wall option was eventually chosen because the temporary works to retain the failed slope were unnecessary and it could be constructed both rapidly and solely from the westbound carriageway. The construction method used is the installation of mini piles because the entire procedure was designed to cope the confined working space. Piling was done by using the mechanical crawler rig . Conventionally, the piles installation is generally carried out in two steps. First the hole is drilled and the drilling apparatus is extracted then the pile is emplaced. This single pass installation has two advantages in terms of quicker installation and concurrent reduction activity. ODEX method (eccentric technique) is a complicated drilling technique, which allows the casing tube to be driven into the hole while it is being drilled, without having to be rotated. A pilot bit drill at the bottom of the hole wand when rotation begins, the eccentric reamer swings out automatically and enlarges the hole to the correct diameter. As the drill hole advances, tubular casing continuously follows immediately behind the drillhead down to the hole. When the targeted depth is reached and drilling is completed, the drill stem is rotated in the reversed direction so that the eccentric reamer retracts to a position, which is smaller than the inner diameter of the casing. The entire drill string can thus be easily withdrawn through the inside of the casing tube, leaving the latter socketed into bedrock.

Mini pile wall involved a 13 m long row of 28 vertical mini-piles (220 mm diameter) spaced at 450 mm centers , leaving a gap of 230 mm between piles and taken to a minimum depth of 5 m. Vertical piles are restrained by five raking tension piles (170 mm diameter) angle at 45 degree, spaced at 2.25 m centers and advanced to length of 7 m. Both vertical and raking piles are embedded and anchored respectively into the Silurian mudstone and siltstone stratum to depths of between 2.5 m and 3 m below engineering rockhead. Outer shell of the piles consists of a permanent, circular tube of steel casing (220 mm o.d). To provide reinforcement, vertical piles contains a second string of casing (139 mm o.d ., 5 mm wall thickness) and raking piles enclose a macalloy steel bar (single steel tendon prefabricated ground anchor , 20 mm diameter, ultimate strength of 345 kN and double corrosion protection). The piles finally cast in situ using ordinary 40 N/mm2 Portland cement grout. The vertical raking piles are connected by a 0.45 m square, 13.5 m long reinforced concrete capping beam. Overall design is sufficient to withstand a horizontal disturbing force of 60 kN/m generated from the retained slope. This force also include a factor of safety of 1.4 against slope failure.

On the completion of the structural works, wall reinstatement was finalized with the reconstruction of some 6 m of stone facia to a thickness of about 0.5 m with random cemented stonework. Weepholes made of uPVC pipe (25 mm diameter) were installed within the wall at regular intervals. Reprofiling operations were carried out on the slope and the landscaping works were undertaken within the terrace garden area of Hafan Deg.

During and after construction, readings were collected daily at 13 subsidence-monitoring stations. Throughout the construction work, the reading generally indicated an overall static situation.

3. Methodology

The method used by the author is by searching through the website, which related to the research topic. Besides that, finding the related book for this topic is another source as well to obtain extra information and explanation about the topic. Samples of related website are

a. National Hazard And Earth Science Systems.com/ NHESS.com
b. American Society of Civil Engineers.com/ASCE.com
c. www.elsevier.com
d. Institute of Civil Engineering/ ICE.com

Some of the findings were obtained from search engine mostly from Google search.

4. Expected findings.

The expectation from this research is able to comprehend the usage and the specific purpose of each mitigation measures besides tabulate it into a table form and differentiate the various kinds of landslides and its suitable solution.

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CHAPTER 3

CLASSIFICATION OF LANDSLIDES

3.1 Introduction

The next stage of this topic is to classify all the structural mitigation measures into its respective landslide type. In this classification, the landslide are divided into 6 type which are fall , topples, slides, spreads, flows, and complex. Each of this material is divided into three types of failure, which are earth, debris and rock. For example, the classification for fall is **rock fall, debris fall and earth fall.** Following the same trend, this are applied to the next 5 of the failure type.

The 3 type of failure which are rock, earth and debris are differ from the material it transport and the liquidity of the material that it transport. The definition for debris flow taken from Guide To Road Slope Protection Works is, "debris flow consisting of rapid flow of boulder, gravel, silt and clay mixed with a large quantity of water is mainly generated by slope collapse and heavy rainfall. It flows down the riverbed with gradient of over 20-degrees and stops to deposit with gradient of under 10-degrees", <http://dor.gov.np/documents/Guide_To_Road_Slope_Proctection_Works_Ch_2.pdf>. So, the other two type of failure depends on the liquidity of the flow, velocity of the flow, and the material carried away during the landslide. In tropic climate such as in equator area for example in Asia and South America, where rain become the major factor of landslide, most classes of the landslide are debris and earth. Rock failure can be due to erosion factor such as heat, freeze and thaw, earthquake and etc.

The classification of mitigation is based on the journals that had being studied and classified based on its suitability of each mitigation. Some of the mitigation options are based on the area, environment, and cost.

Table 2. A brief list of landslide remedial measures

1. MODIFICATION OF SLOPE GEOMETRY
1.1. Removing material from the area driving the landslide (with possible substitution by lightweight fill) 1.2. Adding material to the area maintaining stability (counterweight berm or fill) 1.3. Reducing general slope angle
2. DRAINAGE
2.1. Surface drains to divert water from flowing onto the slide area (collecting ditches and pipes) 2.2. Shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics) 2.3. Buttress counterforts of coarse-grained materials (hydrological effect) 2.4. Vertical (small diameter) boreholes with pumping or self draining 2.5. Vertical (large diameter) wells with gravity draining 2.6. Subhorizontal or subvertical boreholes 2.7. Drainage tunnels, galleries or adits 2.8. Vacuum dewatering 2.9. Drainage by siphoning 2.10. Electro-osmotic dewatering 2.11. Vegetation planting (hydrological effect)
3. RETAINING STRUCTURES
3.1. Gravity retaining walls 3.2. Crib-block walls 3.3. Gabion walls 3.4. Passive piles, piers and caissons 3.5. Cast-in situ reinforced concrete walls 3.6. Reinforced earth retaining structures with strip/ sheet - polymer/metallic reinforcement elements 3.7. Buttress counterforts of coarse-grained material (mechanical effect) 3.8. Retention nets for rock slope faces 3.9. Rockfall attenuation or stopping systems (rocktrap ditches, benches,fences and walls) 3.10. Protective rock/concrete blocks against erosion
4. INTERNAL SLOPE REINFORCEMENT
4.1. Rock bolts 4.2. Micropiles 4.3. Soil nailing 4.4. Anchors (prestressed or not) 4.5. Grouting 4.6. Stone or lime/cement columns 4.7. Heat treatment 4.8. Freezing 4.9. Electroosmotic anchors 4.10. Vegetation planting (root strength mechanical effect)

Source taken from M. E.Popescu, " Landslide Causal factors and Remediatial Options", http://www.geoengineer.org/Lanslides-Popescu.pdf

3.1.1 Rockslide mitigation

Rockslide can be classified into 3 categories which are rock fall, rock topple and rock slide. For rock fall, the most appropriate mitigation, which are rock anchors, reinforced concrete shed, rock nets, and geogrid embankments. The geogrid embankments can be used as a barrier at the toe of the fall, which act as a energy absorption during the fall. This can be proven by the journal wrote by D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Department of Land, Environment and Geo-technology, Politecno di Torino, Turin, Italy, Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009.

For rock earth, the suitable mitigation option for this are pile, drilled piers, soil nail, retaining wall, toe berm, vegetal protection, surface and shallow trench drain and biotechnical slope stabilization. The reason for the selection for this kind of mitigation is due to environment purposes, degree of suitability, and the material of failure. Degree of suitability in this term is the place and the suitable mitigation option adopted. Some place might have 2-3 mitigation option in order to contain the failure successfully.

In rock debris, the most material carried away in this failure is rock and some earth consisting with high liquidity of water. The origin can be from high rainfall intensity. Most preferable mitigation are slit dam, surface and shallow trench drain, pile, slope adjustment, soil nail, horizontal drain, pre-stressed anchors, retention nets, and geogrid reinforced embankments.

3.1.2 Topple failure mitigation

For topple kind of failure, the movement is collapsing vertically with an axis of rotation at the bottom of the slice. The scouring can be seen at the top of the failure surface itself.

Rock topple mainly consists of rock itself. The size can be huge ranging from boulder or a slab depending on the failure plane orientation. Reason of this failure is due to heat, erosion, earthquakes, tectonic lifts, and many more. Mitigation option for this failure are rock anchors, removal of the failure piece, reinforce concrete shed, net fences, cement grouting, pre-stressed anchors, horizontal drain, gabion, rock bolts and surface drainage. Reason for using internal slope reinforcement is due to its properties that can with hold the failure part or to reinforce it to become more stable. Drainage itself plays very important role in order to prevent or to reduce the rate of infiltration.

Earth topple is mainly consists of earth material but low liquidity. Most preferred mitigation are retaining wall, gabion, cantilever wall, gravity wall, horizontal and vertical drain, surface drainage, vegetal protection, soil nail, pre-stressed anchors, and mechanically stabilized wall (MSW). Debris topple also is applicable to use this kind of mitigation. Application of the soil nail and MSW is taken from the journal John. P. Turner and Wayne G. Jensen, " Landslide Stabilization Using Soil nail wall and mechanical stabilized earth walls", Journal of Geotechnical and Geonvironmental Engineering, Vol. 131, No. 2, February 1, 2005.

3.1.3 Rotational slides mitigation

Rotational failure is a deep-seated landslide and it has its own of axis of rotation. Here there are several parts of the slide itself such as the head, body, and the toe. For each part, there are several mitigation options on it.

Most of it consists of drainage such as horizontal and vertical drain, surface drain, and drainage well. Drainage well can be dig using boring machine. Function of these drain structure is to reduce pore water pressure inside the soil and soil saturation.

Internal slope reinforcement can be rock anchors, micro piles, soil nail and pre-stressed anchors. For retaining structure, it consists of drilled piers, pile, retaining wall, gabion, cantilever wall, and protective concrete block.

For material such as debris and earth, slit dam is constructed at the far end of the toe in case to catch the remaining material after the mitigation structure is built.

3.1.4 Translational slides mitigation

Translational slides failure happens at a horizontal plane. For translational rock failure, the same mitigation is adopted from rotational slides.

3.1.5 Spreads mitigation

For spreads, the failure is consist of earth and rock in a single group and earth spreads in single group. The form of this failure movement is most likely in a horizontal form.

For mitigation measures, slope adjustment, slope vegetation, piling, gabion, sheet pile, surface, horizontal, and shallow trench drain retaining wall and buttress counterforts.

3.1.6 Flows mitigation

For flows failure, rock and debris are classified in one group and earth flow is separate. Material carried consists of rock, earth and debris with high amount of water. Suitable mitigation measures are drilled piers, pipe piles, earth dam, micro pile, retention wall, toe berm, slope vegetation, surface and subsurface drainage, and geosynthethic reinforced.

Earth flow mitigation can be slit dam, earth dam, diversion channel, slope vegetation, retaining wall with anchors, drainage wall, surface and subsurface drainage, and MSE with reinforce geosynthetic

3.1.7 Complex landslide failure

Complex type of landslides may consist of two or three type of movement and material carried. For example, slump-earth flow with rock fall debris and half part translational and rotational movement kind of landslide with earth flow at toe. The remedy for this kind of landslide maybe arbitrary but it mainly consists of drainage, retention structures, internal slope reinforcement, and slope angle adjustment. Choices can be such as

1. Piles
2. Horizontal and vertical drain
3. Soil nail

4. Gabion walls
5. Shallow trench drains
6. Pre Stressed Anchors
7. Drainage shaft
8. Concrete pile wall
9. Vegetation treatment
10. Toe berm
11. Micro pile
12. -Drain arrays
13. Vertical sand drains
14. Toe protection(Drainage blanket and sand drain)
15. Collector drain
16. Draining well
17. Vertical Drainage
18. Surface drainage
19. Vertical and horizontal drain
20. Drainage tunnels

CHAPTER 4

DETAILED SPECIFIC MITIGATION

4.1 Introduction

In this chapter, the classification is more specified. Each mitigation is more detailed which consists of the type of the mitigation, construction method, application and the references. Same classification is used on Chapter 3 but in more detail form.

For structures, drainage and internal slope reinforcement, the method of statement are detailed and some are briefly stated based on the source obtain from the internet. Most of the source consists from the journal and from the construction manual by the company who have expertise in this field.

There are 12 types of retaining structures, which are piles, reinforced concrete shed, gabion, drilled piers, sheet piles, bored piles, H-piles, gravity wall, cantilever wall, mechanically stabilized earth (MSE), retention nets, and geogrid reinforced embankments.

Drainage structures consists of buttress counterfort (drainage effect), horizontal and vertical drain, surface drain, slit dam/ earth dam, drainage wells and tunnels, and shallow trench drain. These structures are adopted from the journal

1. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997
2. <http://www.geoengineer.org/Lanslides-Popescu.pdf>.
3. <http://www.tuat.ac.jp/~sabo/lj/ljap4.htm>.

Internal slope reinforcement has five types that are soil nail, micro-pile, pre-stressed anchors, rock anchors, and rock bolts. Most of the references are taken from

1. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997

2. <http://www.geoengineer.org/Lanslides-Popescu.pdf>.

3. John. P. Turner and Wayne G. Jensen, " Landslide Stabilization Using Soil nail wall and mechanical stabilized earth walls", Journal of Geotechnical and Geonvironmental Engineering, Vol. 131, No. 2, February 1, 2005.

4.2 RETAINING STRUCTURE

4.2.1 Piling

For piling structure, the construction method is taken from the journal "Design and Construction of Driven Pile Foundations-Lesson Learned on the Central Artery/ Tunnel Project", FHWA-HRT-05-159, June 2006.
<http://www.fhwa.dot.gov/engineering/geotech/pubs/05159/05159.pdf>.

This journal elaborates more on how they driven the pile specifically from positioning of the pile, driving of the pile, and lastly rechecking of the pile driven. Applicability of this is for deep-seated landslide such as rotational slope failure in the body part of the landslide.

4.2.2 Reinforced concrete shed

Construction method for this structure is in general form due to difficulty in finding the suitable method of construction. The application of this is for rockfall prone areas such as in the hilly mountain area where unstable rock formation exists and where roads are built nearby the hilly rocks.

4.2.3 Net fences/ Rock nets

Net fences method of construction is in the form of more generalized method and the applicability of it is towards to rock fall. The usage is more to boulder entrapment or in highly rock and earth debris, it can be a catchment fence as well to prevent the debris from blocking or damaging the culvert.

4.2.4 Gabion

Gabion is a structure that consist a single block of wired steel mesh in a rectangular form fill with graded boulders. This structure when stack together can become a retention structure at the toe of the landslide. It can restraint on several meter of heights and type of landslide. Suitability for landslide type can be deep and shallow type of landslide.

4.2.5 Drilled piers

In drilled piers, the structure is augered and cast in-situ. The processes involve by digging up the earth at the targeted depth, casing installation, rebar, and concrete placement. The application of this can be in the deep-seated landslide, complex landslide, flows and topple type of landslide.

Advantage of this structure is that it eliminates the sound pollution by not driving the piers using pile machines. This is an edge for the construction especially where nearby structure concern is.

4.2.6 H-pile

For H-pile, the method of construction is taken from the <http://www.intrafor.com/intrafor/workfiles/HongKong/ITF_PIP_Junvenile_Tuen_Mun.pdf>. This method of installation is the same for the sheet pile wall. Suitability for this mitigation is for the propping purposes in underground excavation, toe protection for deep seated and shallow landslides as well.

4.2.7 Bored-pile

In bore pile, the pile is constructed in-situ. This can save the cost in terms of mobilization. Application for this mitigation can be for as retention structures for deep-seated landslides for example in rotational or translational type and for drainage well construction.

4.2.8 Gravity wall

In gravity wall, the application of this wall is for shallow-seated landslide. This can be applied in earth and debris topple, earth and debris fall and for deep-seated landslides, it can be as a toe retention structures plus with drainage system.

Construction technique was written in general form due to difficulty to find information about this wall.

4.2.9 Cantilever wall

The cantilever wall is for flows, translational and complex type of landslides. The material consists of earth and debris. This structure have pile driven into the soil to overcome the passive pressure at the upper region/ area of the slides plus with drainage structures such as wells, slit dam, and draining ditch.

This method is taken from the journal written by the authors A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from

Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006.

4.2.10 Mechanically Stabilized Earth

This structure is used for the construction for additional road lane. This can be seen by the published journal from John. P. Turner and Wayne G. Jensen, " Landslide Stabilization Using Soil nail wall and mechanical stabilized earth walls", Journal of Geotechnical and Geonvironmental Engineering, Vol. 131, No. 2, February 1, 2005. In this journal, it combines with the soil nail to make it stable. The MSE is used for the new lane for the road construction.

4.2.11. Geogrid Reinforced Embankment

The construction method for this method is taken from the website <www.airvolblock.com>. and the journal F. Tatsuoka, M. Tateyama, Y. Mohri, K. Matsushima, " Remedial treatment of soil structures using geosynthetic- reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220 repectively.

This remedial measure can be used as an reinforced soil tool by without constructing retention structures by adding drainage and internal slope reinforcement depending on the case.

4.2.12 Toe berm

This function for this structure is for toe protection especially in deep and complex type of landslide. It react as the same as gabion but it can be used as a road structure on top of the berm with related reinforced mitigation such as geogrid, pile, and etc

4.3 INTERNAL SLOPE REINFORCEMENT

4.3.1 Rock anchors

This mitigation measure is used in rock fall kind of failure and for the underground tunnel construction. The idea of this is to make the rock as stable as it can so that the future structure that will be building is safe.

Related journal for this kind of mitigation are

1. W.L. Schroeder and D.N. Swanston, "Installation and Use of Epoxy-Grouted Rock Anchors for Skyline Logging in - Southeast Alaska", United States Department of Agriculture , Pacific Northwest Research Station General Technical Report, PNW-GTR-297, April 1992

2. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.

3. <http://www.geoengineer.org/Lanslides-Popescu.pdf>.

4.3.2 Pre-stressed ground anchors

This mitigation is used for rock reinforcement. There are reasons why soil nail and ground anchors are adopted differently depending on the situation. One of the journal written by , J Suguwara, "Soil Nailing Technology and Japanese Landslide Mitigation Works", Geo-Singapore 2006 : An International Conference on Geotechnical Engineering, 11-13 December 2006, Singapore, stated that " One of the main reasons that the ground anchoring tends to be more economical than the soil nailing may be explained by the pre-stress in the ground anchoring. As known, the pre-stress provides an active restraint, enabling the anchor to resist service loadings and control displacements. Particularly when the required end force to enhance the factor of safety is large, the number of drilling holes required in the ground anchoring scheme could be significantly fewer than in the soil nailing scheme as the ground anchoring develops resisting force by applying the pre-stress. The ground anchoring may therefore be more cost effective than the soil nailing particularly when the size of slope failure is relatively large."

The advantage for this mitigation measure is that, it can stabilize the slopes without allowing more deformations in the unstable rock mass.

4.3.3 Rock bolts

Rock bolts have the same function as rock anchors. The degree of suitability depends on the environment, cost, and function of the construction. It can vary in length depending on what it would use such as bridge or road construction, which is situated underground. It is used as rock reinforcement for weak rock strata. References for this mitigation are obtained from

1. <http://graceandpearmanbridge.org/papers/CableBoltAnchors.pdf>.

2. <http://www.geoengineer.org/Lanslides-Popescu.pdf>.

3. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.

4.3.4 Soil nail

Soil nail works as same as ground anchors but in terms of quantity, it require more quantity than the ground anchor. The reason is stated in the journal written by J Suguwara, "Soil Nailing Technology and Japanese Landslide Mitigation Works", Geo-Singapore 2006 : An International Conference on Geotechnical Engineering, 11-13 December 2006, Singapore, stated that " One of the main reasons that the ground anchoring tends to be more economical than the soil nailing may be explained by the pre-stress in the ground anchoring.

As known, the pre-stress provides an active restraint, enabling the anchor to resist service loadings and control displacements. Particularly when the required end force to enhance the factor of safety is large, the number of drilling holes required in the ground anchoring scheme could be significantly fewer than in the soil nailing scheme as the ground anchoring develops resisting force by applying the pre-stress. The ground anchoring may therefore be more cost effective than the soil nailing particularly when the size of slope failure is relatively large."

Besides, the cost plays an important role as well for this mitigation option.

4.3.5 Micro-pile

The micro-pile is used as a foundation for the retaining wall. In this method of installation, the pile is bored using wash boring method and if collapsible area is encountered, the casing method is adopted.

This pile is driven using the piling machine. The micro-pile makes the retaining wall become more passive resistance in terms of pressure. This can be seen by the journal written by A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G.

Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006

In this journal, the pile is used as a foundation in order to retain the earth flow combines with earth and slit dam.

4.4 DRAINAGE

4.4.1 Drainage well

This structure is used for the deep-seated landslide type. Function is to reduce the pore water pressure inside of the slide where the water table is deep. This can be seen by the journal written by E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.

In his journal, in the deep-seated landslide in Japan, at Zentoku Island, the drainage plays an important role as pore water reducers besides with other retaining and internal slope reinforcement system.

4.4.2 Surface and shallow trench drain

The function of this drain is to remove water at the surface of the landslide. By removing water at the surface level, it can reduce water infiltration hence reduces the pore water pressure. Water reduction at the slope will make the slope become more stable. The setback of this option is that it needs periodical maintenance in order it to fully functional because this structure tends to clogged.

4.4.3 Horizontal drain

The insertion of drainpipe to intersect the groundwater flow of the slice failure is the main function for this draining option. It can be applied for deep or shallow type of landslides. Identification of the groundwater flow can be trace and identified by draining well and borehole that been dug when the geotechnical investigation is been conducted.

4.4.4 Slit dam

The usage of slit dam is to retain debris or earth flow without damaging the culvert downstream. Application of this structure is been applied on various journals such as

1. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.
2. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006.
3. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989.

4.4.5 Buttress Counterforts.

This mitigation can be used as a retention system or a drainage structure. This is because, based on the mitigation option that are exist in the table, it can be used both way. This is due to its mechanical and its hydrological effect. It can be combined with drainage and other internal reinforcement system that will make the mitigation much more efficient.

4.5 References

A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006.

C. Ronco, C. Oggeli, and D. Peila, "Design of reinforced ground embankments used for rockfall protection," Department of Land, Environment and Geo-technology, Politecno di Torino, Turin, Italy, Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009

D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Department of Land, Environment and Geo-technology, Politecno di Torino, Turin, Italy, Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009

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F. Tatsuoka, M. Tateyama, Y. Mohri, K. Matsushima, " Remedial treatment of soil structures using geosynthetic- reinforced technology", Geotextiles and Geomembranes 25(2007) 204-220.

<http://www.contech.co.nz/uploaded/A%20Review%20of%20Ground%20Anchor%20Practice%20in%20New%20Zealand%20-%20March%20_.pdf>.

<http://graceandpearmanbridge.org/papers/CableBoltAnchors.pdf>.

<http://www.judycompany.com/engineer/articles/betterroads-0309.pdf>.

<http://www.intrafor.com/intrafor/workfiles/HongKong/ITF_PIP_Junvenile_Tuen_Mun.pdf>.

<http://www.lta.gov.sg/projects/images/CBP%20Final.pdfhttp://geoprofound.com/download/mst-all.pdf>.

<http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.

<http://www.iowadot.gov/erl/current/CM/content/6-40.pdf>.

<http://www.tuat.ac.jp/~sabo/lj/ljap4.htm>.

John. P. Turner and Wayne G. Jensen, " Landslide Stabilization Using Soil nail wall and mechanical stabilized earth walls", Journal of Geotechnical and Geonvironmental Engineering, Vol. 131, No. 2, February 1, 2005.

Jun Sun[a], Sijing Wang[b], "Rock mechanics and rock engineering in China: developments and current state-of- the- art," [a] Tongji University, Shanghai, 200092, People's Republic of China, [b] Institute of Geology, China Academy of Sciences, Beijing, 100029, People's Republic of China, International Journal of Rock Mechanics and Mining Sciences 37 (2000), 447-465, 21 Sept, 1996.

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<http://www.geoengineer.org/Lanslides-Popescu.pdf>.

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

For this chapter, the author can conclude that the mitigation classification and description in detailed have successfully reached its objectives. Based on the catalogue and detailed mitigation description on each mitigation, the author have successfully defined each technique based on the suitability and type of landslides.

For the recommendation, in the next research for this topic, the next author can defined in more detailed whether from design stage of the mitigation, soil properties, and other geotechnical properties that will suit each mitigation specifically to its characteristics. Besides that, the advantage and disadvantage can be put in as well to compare which one is the best compare to other mitigation technique. Maintainability of each mitigation can be put as well, so the next person who use can understand or have and idea on how to take care on each mitigation.

CHAPTER 6

ECONOMIC BENEFITS

In this research, there are no cost included since this work is mostly conducted by reviewing and compiling related journals to the research title. In terms of advantage for this topic, it can be viewed in terms of two aspects.

Since the mitigation is the most important solution for every landslide event, it actually reduce the losses of the inhabitants and also the structure situated below the landslide area. It can be conclude that by decreasing the number of death toll and also infrastructure damage. By doing so, chances of development for the area or chances of people's activity can be increase and indirectly it can contribute to the economic growth of the area. This can be proved by the journal written by D.Nichol and R.D.W. Lowman titled "Stabilization and remediation of a minor landslide affecting the A5 trunk road at Llangollen, North Wales, UK". The mitigation used was using mini-piles and this remediation measures has helped the road to be reopened again to the public which connecting Dublin and UK.

Another proved can be seen from the journal written by A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006. The remediation used was retaining wall, draining wells, earth dam, and piles. Due to from this mitigation, they successfully contain this mother nature because the area is an important road serving the upper watershed area of River Secchia where many villagers and key industrial facilities are located.

The other benefit is that it can reduce the cost by selecting the most appropriate mitigation. The cost is mostly influenced by the selection method and also type of landslides. In the journal written by A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern

Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006, the cost for the mitigation is 3, 000, 000 Euro which is an affordable and politically sustainable by the public boards. Selection are also influenced by the geotechnical investigation which are the earlier preventive steps to select the mitigation measures. Investigation method used are seismic surveys and boreholes, core sampling, permeability test and laboratory analysis of the boreholes. In China, the method adopted are by using geotechnical and hydrological investigations, in situ tests and stability analysis. From this they adopting the dynamic comprehensive control method which to control further the degradation of the sliding surface thus reducing the total cost of the construction.

Another factor that is contributing for the cost effectiveness of the mitigation are assessment of Stability Margin, risk, uncertainty, possible consequences, constructability, environmental impacts, and lastly short and long term performance of the mitigation.

CATALOGUE OF STRUCTURAL MITIGATION

In this section, the mitigations are classified based on each failure. It include from structural, internal slope reinforcement and drainage. The classification are been put in tabular form and the selection for each failure are arbitrary. In the catalogue, the types of the failure are in the left corner of the table while the suitable mitigation is at the center of the table and lastly, the references are at the right of the table.

References are taken from the related journal of each mitigation depending on the type of failure for each landslide. The mitigation is covered in terms of shallow and deep-seated type of landslides.

CATALOGUE OF STRUCTURAL LANDSLIDE MITIGATION

	Material	Mitigation Measures	Reference
Movement Type			
	Rock	1. Rock anchors 2. Reinforce concrete shed 3. Net Fences 4. Cement Grouting 5. Pre stressed Anchors 6. Horizontal Drain 7. Reinforced Geogrid embankments 8. Gabion 9. Rock bolts	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009. 4. C. Ronco, C. Oggeli, and D. Peila, "Design of reinforced ground embankments used for rockfall protection," Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009. 5. Jun Sun[a], Sijing Wang[b], "Rock mechanics and rock engineering in China: developments and current state-of- the- art," [a] Tongji University, Shanghai, 200092, People's Republic of China, [b] Institute of Geology, China Academy of Sciences, Beijing, 100029, People's Republic of China, International Journal of Rock Mechanics and Mining Sciences 37 (2000), 447-465, 21 Sept, 1996.
FALL			
	Debris	1. Piled(H-pile/	

		Bore pile/ Micro pile) 2. Drilled Piers 3. Soil Nail 4. Slope adjustment 5. Retaining Wall (at toe) 6. Toe Berm 7. Vegetal Protection 8. Surface and shallow trench drain 9. Biotechnical Slope stabilization	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. Aaron S. Bradshaw and Christopher D. P. Baxter. Design and Construction of Driven Pile Foundations-Lesson Learned on the Central Artery/ Tunnel Project. FHWA-HRT-05-159, University of Rhode Island Narragansett, RI 02882
	Earth	1. Piled(H-pile/ Bore pile/ Micro pile) 2. Drilled Piers	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide

		3. Soil Nail 4. Slope adjustment 5. Retaining Wall (at toe) 6. Toe Berm 7. Vegetal Protection 8. Surface and shallow trench drain 9. Biotechnical Slope stabilization	Remediatial Options," <http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. Aaron S. Bradshaw and Christopher D.P. Baxter. Design and Construction of Driven Pile Foundations-Lesson Learned on the Central Artery/ Tunnel Project. FHWA-HRT-05-159, University of Rhode Island Narragansett, RI 02882
TOPPLE	Rock	1. Rock anchors 2. Reinforce concrete shed 3. Net Fences 4. Cement Grouting	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options," <http://www.geoengineer.org/Lanslides-Popescu.pdf>.

		5. Pre stressed Anchors 6. Horizontal Drain 7. Reinforced Geogrid embankments 8. Gabion 9. Rock bolts 10. Surface drainage	3. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline,", Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009 4. C. Ronco, C. Oggeli, and D. Peila, "Design of reinforced ground embankments used for rockfall protection,". Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009 5. Jun Sun[a], Sijing Wang[b], "Rock mechanics and rock engineering in China: developments and current state-of- the- art," [a] Tongji University, Shanghai, 200092, People's Republic of China, [b] Institute of Geology, China Academy of Sciences, Beijing, 100029, People's Republic of China, International Journal of Rock Mechanics and Mining Sciences 37 (2000), 447-465, 21 Sept, 1996.
	Debris	1. Soil nail 2. Slope adjustment 3. Horizontal Drain 4. Buttress Counterforts 5. Gravity wall	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25

		6. Gabions 7. Surface Drain 8. Shallow or deep trench drain 9. Vegetation planting 10. Toe berm 11. Mechanically Stabilized Earth	(2007) 204-220.
	Earth	1. Retaining wall 2. Soil nail and Mechanically Stabilized Earth (MSE) wall 3. Horizontal Drain 4. Buttress Counterforts 5. Gravity wall	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220. 4. John. P. Turner and Wayne G. Jensen, " Landslide Stabilization Using Soil nail wall and mechanical stabilized earth walls", Journal

		6. Surface drain 7. Shallow or deep trench drain 8. Vegetation planting	of Geotechnical and Geonvironmental Engineering, Vol. 131, No. 2, February 1, 2005.
	TRANSLATIONAL		
SLIDES			
	Rock	1. Reinforce concrete shed 2. Cement grouting 3. Rock anchors 4. Pre stressed Anchors 5. Reinforced ground embankments 6. Draining well 7. Horizontal and vertical well 8. Rock bolts	1. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options," http://www.geoengineer.org/Lanslides-Popescu.pdf 3. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009 4. C. Ronco, C. Oggeli, and D. Peila, "Design of reinforced ground embankments used for rockfall protection,", Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009

		9. Wire mesh 10. Retention nets 11. Buttress Counterforts 12. Slope adjustments	
	Debris	1. Buttress counterforts 2. Piling 3. Drilled piers 4. Gravity wall 5. Retaining wall 6. Soil nail 7. Pre stressed anchor 8. Head and scarp removal	1. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. F. Tatsuoka, M. Tateyama, Y. Mohri, K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220. 4. Aaron S. Bradshaw and Christopher D. P. Baxter. Design and Construction of Driven Pile Foundations-Lesson Learned on the Central Artery/ Tunnel Project. FHWA-HRT-05-159, University of Rhode Island Narragansett, RI 02882

		9. Vegetation planting 10. Horizontal and vertical drain 11. Draining well 12. Surface drainage 13. Draining tunnels	5. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006.
	Earth	1. Geosynthetic reinforced Technology 2. Pipe piles and wood lagging 3. Geogrids repair 4. Soil nail and MSE wall 5. Shortcrete 6. Vertical and horizontal drain	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options," <http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220. 4. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of

		7. Surface drainage 8. Drainage well 9. Retention wall 10. Slit dam 11. Earth dam	the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006. 5. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989.
	ROTATIONAL		
	Rock	1. Mini pile wall 2. Pile 3. Soil nail 4. Pre stressed anchor 5. Retaining wall 6. Buttress Counterforts 7. Drilled piers 8. Earth Dam	1. E. N. Bromhead, "The Treatment of Landslides ," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options," <http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009 4. C. Ronco, C. Oggeli and D. Peila, "Design of reinforced ground embankments used for rockfall protection," Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009

		9. Protective rock or concrete berm 10. Horizontal and vertical drain 11. Draining well 12. Drainage tunnel 13. Surface drainage 14. Slope vegetation 15. Slope adjustment	5. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989. 6. Wei Zuoan, Li Shihai, J.G. Wang and Wan Ling, " A dynamic comprehensive method for landslide control", Engineering Geology 84 (2006) 1-11
	Debris	1. Mini pile wall 2. Pile 3. Soil nail 4. Pre stressed anchor 5. Retaining wall	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options," <http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of

		6. Buttress Counter forts	the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006.
		7. Drilled piers 8. Earth Dam	4. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989.
		9. Protective rock or concrete berm 10. Horizontal and vertical drain 11. Draining well 12. Drainage tunnel 13. Surface drainage 14. Slope vegetation 15. Slope adjustment	5. Wei Zuoan, Li Shihai, J.G. Wang and Wan Ling, " A dynamic comprehensive method for landslide control", Engineering Geology 84 (2006) 1-11
	Earth	1. Protective rock	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn

		or concrete block 2. Rock berms 3. Earth dam 4. Slope adjustment 5. Retaining wall 6. Buttress Counterforts 7. Drilled piers 8. Horizontal and vertical drain 9. Drainage tunnel and well 10. Slope vegetation 11. Slit dam 12. Drainage well	Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options, < http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006. 4. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989. 5. Wei Zuoan, Li Shihai, J.G. Wang and Wan Ling, " A dynamic comprehensive method for landslide control", Engineering Geology 84 (2006) 1-11.

SPREAD	Rock and debris	1. Piling 2. Gabion 3. Sheet pile 4. Surface drain 5. Shallow trench drain 6. Horizontal drain 7. Retaining wall 8. Buttress counterforts	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options," <http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009 4. C. Ronco, C. Oggeli, and D. Peila, "Design of reinforced ground embankments used for rockfall protection," Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009 5. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25(2007) 204-220. 6. Aaron S. Bradshaw and Christopher D.P. Baxter. Design and Construction of Driven Pile Foundations-Lesson Learned on the Central Artery/ Tunnel Project. FHWA-HRT-05-159, University of Rhode Island Narragansett, RI 02882

	Earth	1. Pile 2. Horizontal drain 3. Pre Stressed anchors 4. Soil nails 5. Gabion 6. Pipe piles or wood lagging 7. Soil cement 8. Geogrid repair 9. Geosynthetic reinforced technology 10. Concrete retaining wall 11. Mini pile wall 12. Surface drain	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options," <http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220.

FLOWS	Rock and debris	1. Drilled piers 2. Pipe piles and wood lagging 3. Earth Dam 4. Micropile 5. Retention wall 6. Toe berm 7. Slope vegetation 8. Surface and subsurface drainage 9. Slit dam 10. Drainage well	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009 4. C. Ronco, C. Oggeli, and D. Peila, "Design of reinforced ground embankments used for rockfall protection,", Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009 5. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220. 6. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006. 7. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989.

	Earth	1. Slit dam 2. Earth dam 3. Concrete lined or diversion channels with water injection 4. Slope vegetation 5. MSE with reinforce geosynthetic 6. Retaining wall with anchors 7. Draining well 8. Surface and subsurface drainage 9. Retaining wall	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220. 4. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006. 5. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989.

Complex	Rock, Debris and Earth	1. Piles 2. Horizontal and vertical drain 3. Soil nail 4. Gabion walls 5. Shallow trench drains 6. Pre Stressed Anchors 7. Drainage shaft 8. Concrete pile wall 9. Vegetation treatment 10. Toe berm 11. Micropile 12. Drain arrays 13. Vertical sand	1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997. 2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"<http://www.geoengineer.org/Lanslides-Popescu.pdf>. 3. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Department of Land, Environment and Geo-technology, Politecno di Torino, Turin, Italy, Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009 4. C. Ronco, C. Oggeli, and D. Peila, "Design of reinforced ground embankments used for rockfall protection," Nat. Hazard Earth Syst. Sci., 9, 1189-1199, 17 July 2009 5. F. Tatsuoka, M. Tateyama, Y. Mohri, and K. Matsushima, " Remedial treatment of soil structures using geosynthetic-reinforced technology", Geotextiles and Geomembranes 25 (2007) 204-220. 6. Aaron S. Bradshaw and Christopher D.P. Baxter. Design and Construction of Driven Pile Foundations-Lesson Learned on the Central Artery/ Tunnel Project. FHWA-HRT-05-159, University of Rhode Island Narragansett, RI 02882 7. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G.

		drains 14. Toe protection(Drainage blanket and sand drain) 15. Collector drain 16. Draining well 17. Vertical Drainage 18. Surface drainage 19. Vertical and horizontal drain 20. Drainage tunnels 21. Slit dam 22. Earth dam 23. Draining ditch 24. Retaining wall	Sartini, and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006. 8. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989.

SPECIFIC MITIGATION DESCRIPTION FOR EACH STRUCTURAL MITIGATION

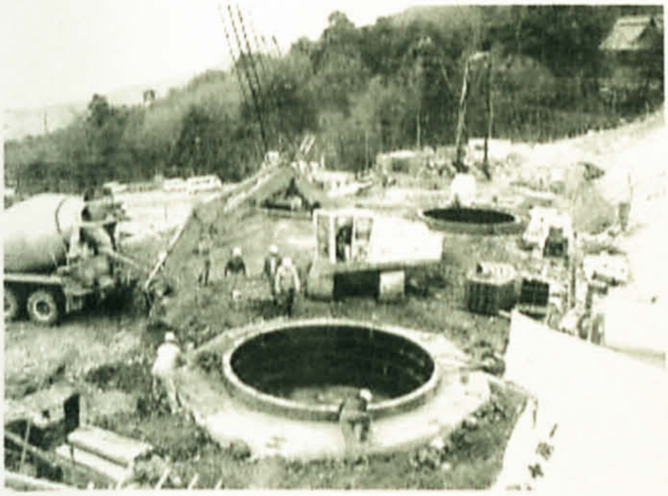
In this section, the mitigations are discussed in more detail in terms of construction method, applicability of the mitigation, and the related references in each mitigation. The construction methods are expressed in general statement and sometimes are in specific instruction taken from related website.

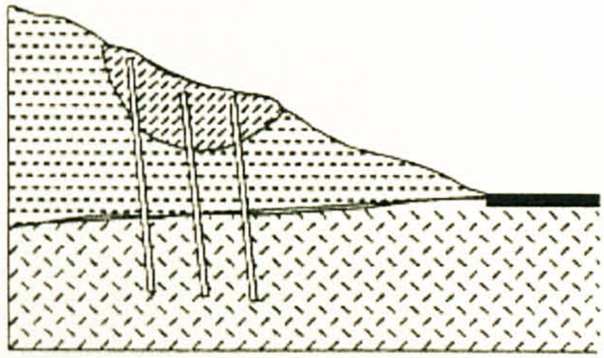
The applicability for each mitigation can be in deep or shallow seated landslide ranging from structure, internal slope reinforcement, and lastly, drainage.

In terms of references, they were taken from reports, websites, and journals. Some of the references provide direct steps on how to construct the mitigation thus is taken from it as construction method.

RETAINING STRUCTURE

Pile





B. Piles used to stabilize shallow rotational landslide

Construction Method

I. For pile driven by machinery

In preparation for driving, a pile is first hoisted to an upright position using the crane and is placed into the leads of the pile driver. The leads are braces that help position the piles in place and maintain alignment of the hammer-pile system so that a concentric blow is delivered to the pile for each impact. Once the pile is positioned at the desired location, the hammer is lowered onto the pile butt. A pile cushion consisting of wood, metal, or composite material is placed between the pile and the hammer prior to driving to reduce stresses within the pile during driving.

Once the pile is in position, pile driving is initiated and the number of hammer blows per 0.3 m of penetration is recorded. Toward the end of driving, blows are recorded for every 2.5 cm of penetration. Pile driving is terminated when a set of driving criteria is met. Pile driving criteria are generally based on the following: (1) the minimum required embedment depth, (2) the minimum number of blows required to achieve capacity, and (3) the maximum number of blows to avoid damage to the pile. All information that is associated with pile driving activities (e.g., hammer types, pile types, pile lengths, blow counts, etc.) is recorded on a pile driving log.

This particular record is for the installation of a 24-m-long, 41-cm-diameter PPC pile installed at the airport as part of contract C07D2. A hydraulic hammer with an 89-kN ram and a 1.2-m stroke was used. The number of blows per 0.3 m of driving was recorded from an embedment depth of 9.5 m to a final depth of 16.5 m. At a depth of 16.5 m, the hammer blows required to drive the pile 2.5 cm were recorded in the righthand column of the record. Driving was stopped after a final blow count of 39 blows per 2.5 cm was recorded.

Once a pile has been installed, the hammer may be used to drive the pile again at a later time. Additional driving that is performed after initial installation is referred to as a redrive or restrike. A redrive may be necessary for two reasons: (1) to evaluate the long-term capacity of the pile (i.e., pile setup or pile relaxation), or (2) to reestablish elevations and capacity in piles that have been subject to heave.

II. For cast in situ pile

1. The hole is augered using augered machinery until at a targeted depth.

2. Casing are then installed to prevent collapse of the soil

3. Reinforce cage are then lowered down

4. Concrete are then poured into the casing

Application

1. Deep seated landslide

Reference

1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997

2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"<http://www.geoengineer.org/Lanslides-Popescu.pdf>.

3. Aaron S. Bradshaw and Christopher D.P. Baxter. Design and Construction of Driven Pile Foundations-Lesson Learned on the Central Artery/ Tunnel Project. FHWA-HRT-05-159, University of Rhode Island Narragansett, RI 02882.

4. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006.

Reinforce concrete shed

Construction Method

1. The place is cleaned up from any further rockfall and debris
2. The formwork and the reinforced concrete were raise up to be built
3. Concrete work were done
4. Putting a soft or energy absorption material on top of the concrete roof.

Application

1. Rockfall prone areas
2. Debris/ Earth flow areas

Reference

1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.

Rock fences/ Wire mesh/ Rock nets

Construction Method

1. The column for the net are raised by air vehicle, eg, helicopter
2. Workers from the upper hill are then installed the column placement and then anchored with cable at the respective area
3. Specific dimensions depending on the span of each column then raise the net and the fences are then been clipped and anchored into the ground for strengthening reasons.

Application

1. Rock fall prone areas/ Hilly terrain with highly eroded rock
2. Debris flow retention area.

References

1. D. Peila and C.Ronco, "Design of rockfall net fences and the ETAG 027 European Guideline," Department of Land, Environment and Geo-technology, Politecno di Torino, Turin, Italy, Nat. Hazard Earth Syst. Sci., 9, 1291-1298, 29 July 2009
2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.

Gabion

Construction Method

1. Before filling, gabions should be placed on the prepared surface and tensioned to ensure that the shape is good and that exposed surfaces are smooth and taut.
2. Filling of gabions with rockfill maybe by machine or hand taking care to minimize voids. However, exposed faces must be filled by hand using selected larger pieces of rock with flat faces to give a fair face to the rockfill inside he exposed geogrid face.
3. If the gabion height is more than 500 mm the cross ties of HDPE braid should be installed at vertical interval of 250-400 mm to improve stability and quality of finish.
4. Slightly over-filled each gabion, using smaller stones on the surface, to allow for settlement. Encourage settlement, for example by walking on the rockfill
5. Adjust finish surface of rockfill as needed.
6. Close down top of gabion and tightly lace all edges and top- diaphragm joints.

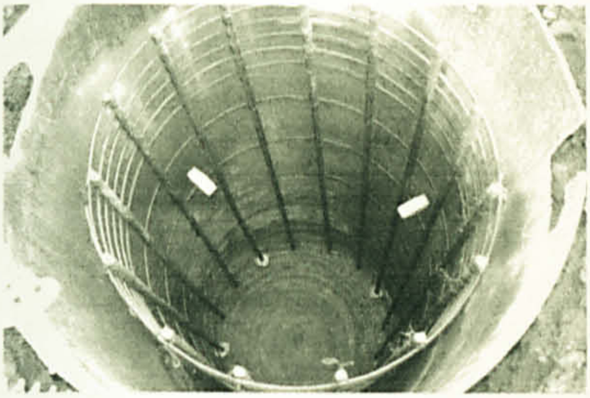
Application

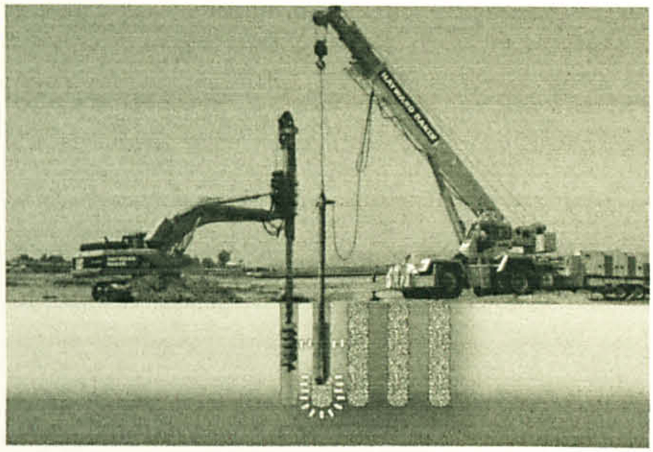
1. Toe protection for shallow and deep seated landslide and rock-fall
2. Toe protection for earth slide

Reference

1. M. E. Popescu, “Landslide Causal Factor And Landslide Remediatial Options,”< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
2. <http://www.newgrids.com/userImages/00000145_Gabion%20and%20Mattress%20Advice%20Aug06.pdf>.

Drilled piers





Construction Method

1. The hole is drilled by drilled auger machine
2. Casing and rebar are put in place respectively
3. Concrete are then poured inside the casing

Application

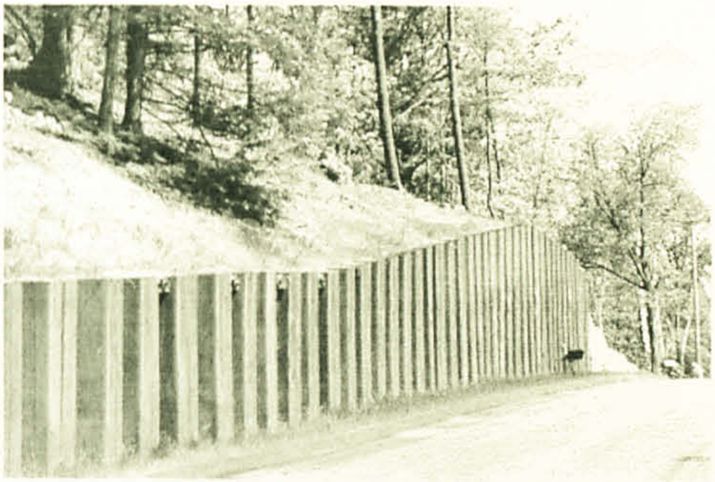
1. For deep seated and complex landslide mitigation
2. Foundation for retaining wall
3. For drainage well construction

Reference

1. Rogers, J. D. , 1992. " Recent developments in landslide mitigation techniques. In Slosson, J.E., Keene, A.G. and Johnson, J.A., eds., Landslides/ Landslide Mitigation: Boulder, Colorado", Geological Society of America Reviews in Engineering Geology, Volume IX, p. 95-118.
2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.

3. Robert W. Day, October 1999, "Design method of slope stabilization with piles", Journal of Geotechnical and Geoenvironmental Engineering, p. 910-920.

H-pile



Construction Method

1. Pitch, align and plumb first pair
2. Drive 1st pair- carefully & accurately pitch remainder of panel
3. Ensure last pair are accurately position and plumbed, drive last pair
4. Drive remainder of panel-working backwards towards 1st pair
5. First panel part driven
6. Second panel pitched. Last pair of first panel become first pair of second panel. Gates supported by thro' bolting to last driven pair.
7. 1st panel driven to final level in stages. Last pair of second panel plumbed & driven accurately.
8. 1st panel completed. 2nd panel part driven, 3rd panel pitched. Last pair of second panel become first pair of 3rd panel

Application

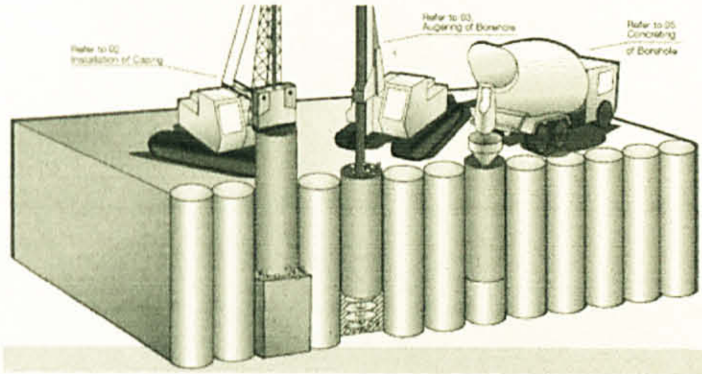
1. For shallow landslides
2. For propping purposes in underground excavation

3. For toe protection in deep seated landslides

References

1. <http://www.intrafor.com/intrafor/workfiles/HongKong/ITF_PIP_Junvenile_Tuen_Mun.pdf>.

Bore-pile



Construction Method

1. Position of the bored pile
2. Installation of the casing
3. Augering of borehole
4. Installation of steel cage
5. Concreting of borehole
6. Extraction of casing
7. Repetition of process

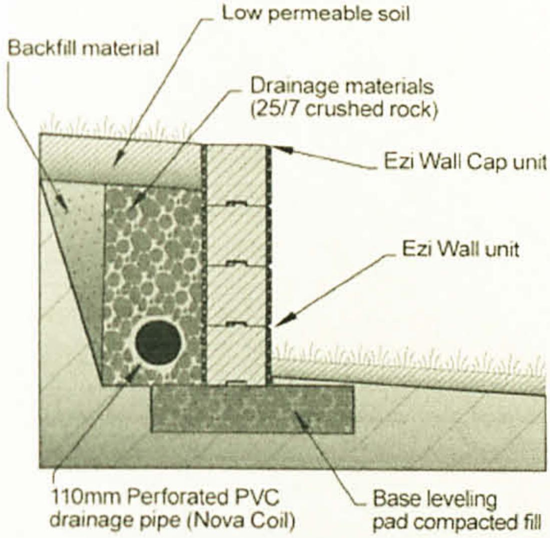
Application

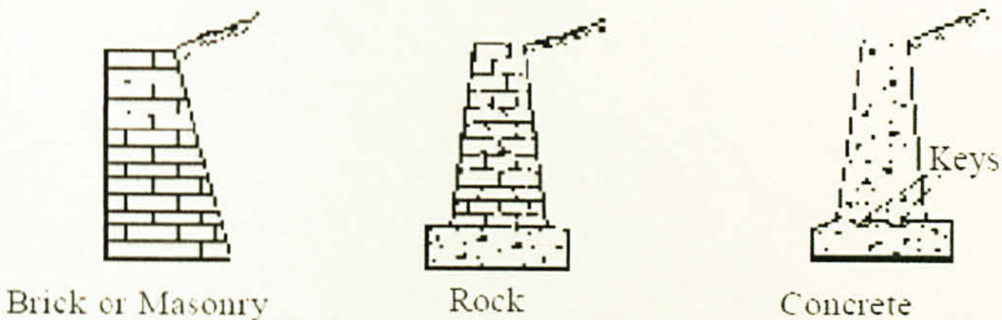
1. Deep seated landslide
2. Construction of the drainage well

References

1. Land Transport Authority. OCT 2004
<http://www.lta.gov.sg/projects/images/CBP%20Final.pdf>.

Gravity wall





Gravity Walls

Construction Method

1. The foundation is first constructed
2. The wall are then raised and installed phase by phase until the targeted height is achieved
3. Drainage material and pipe are then installed at the back of the wall concurrently with the concrete block installation
4. Compaction are then proceed
5. In situ soil are then used for surface finish purposes

Application

1. Toe protection for shallow landslides (debris and earth slides)

Reference

1. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.
2. <http://ntl.bts.gov/lib/24000/24600/24650/Chapters/M_Ch11_Slope_Stabilization.pdf>.

Pile wall / Sheet pile

Construction Method

1. Pitch, align and plumb first pair
2. Drive 1^{st} pair- carefully & accurately pitch remainder of panel
3. Ensure last pair are accurately position and plumbed, drive last pair
4. Drive remainder of panel-working backwards towards 1^{st} pair
5. First panel part driven
6. Second panel pitched. Last pair of first panel become first pair of second panel. Gates supported by thro' bolting to last driven pair.
7. 1^{st} panel driven to final level in stages. Last pair of second panel plumbed & driven accurately.
8. 1^{st} panel completed. 2^{nd} panel part driven, 3^{rd} panel pitched. Last pair of second panel become first pair of 3^{rd} panel

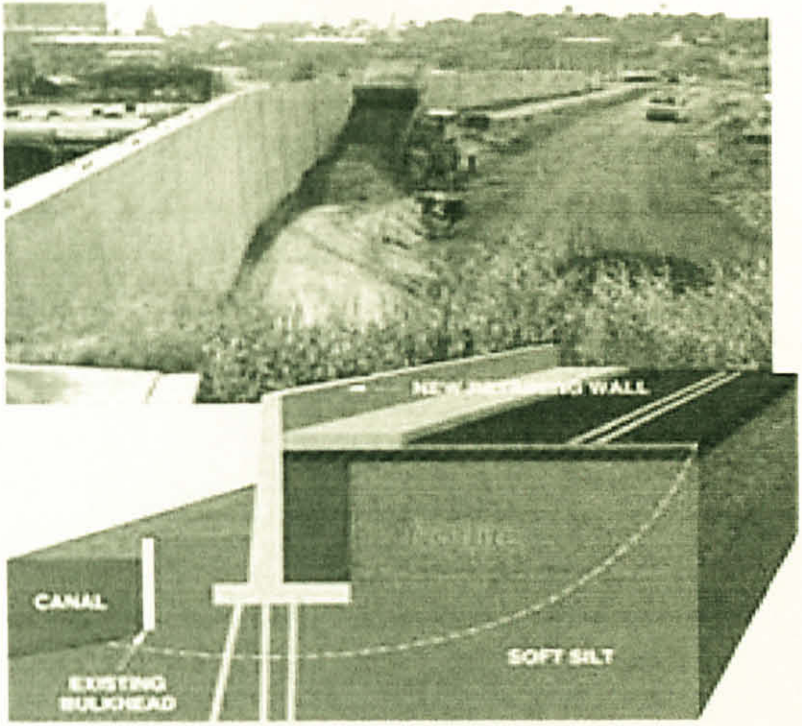
Application

1. Deep excavation
2. Soil retaining structures
3. Water cut-off structures

Reference

1. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.

Cantilever Wall



Construction Method

1. Foundation is first then constructed (piling for deep foundation or just ordinary footing construction)
2. The wall is then constructed after the first phase and the backfill is then fill and compacted concurrently.
3. Drainage is then installed at the stated area of the retaining wall.

Application

1. Toe protection for shallow landslides (debris and earth slides)
2. Retaining wall for shallow landslides

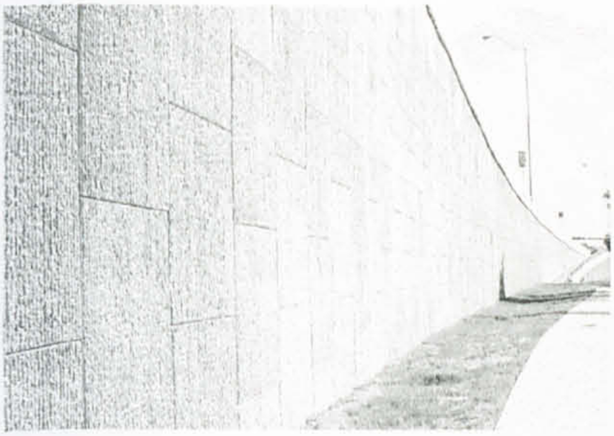
Reference

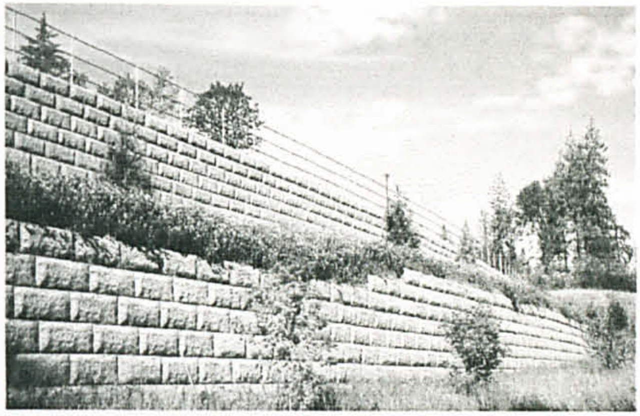
1. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.

2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.

3. A. Corsini, L. Borgatti, G. Caputo, N. De Simone, G. Sartini and G. Truffelli, " Investigation and Monitoring in support of the structural mitigation of large slow moving landslides : an example from Ca'Lita (Northern Apennines, Reggio Emilia, Italy) ", Natural Hazard and Earth System Science, 6, 55-61, 2006.

Mechanical Stabilized Earth (MSE)





Construction Method

1. Foundation of the structure is first then constructed
2. The concrete block/panel is then installed with the drainage structure
3. Backfill is then fill and compacted
4. The procedure 1-3 is repeated until the targeted height is achieved

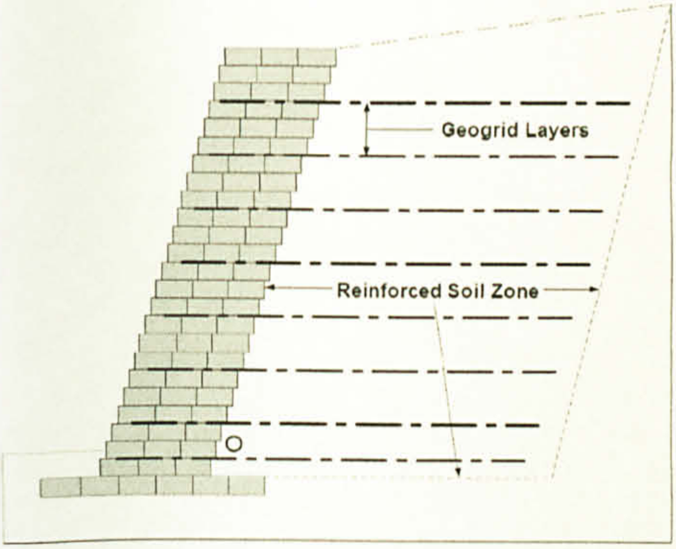
Application

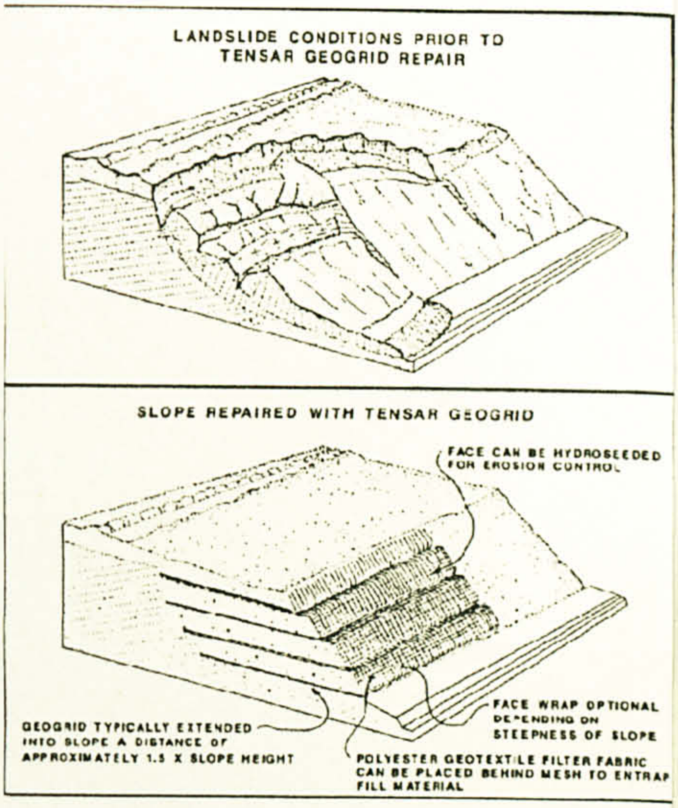
1. For shallow landslides (earth and debris topple, earth and debris slides)
2. For the new lane road construction and bridge abutment.

Reference

1. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
2. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.
3. John. P. Turner and Wayne G. Jensen, " Landslide Stabilization Using Soil nail wall and mechanical stabilized earth walls", Journal of Geotechnical and Geonvironmental Engineering, Vol. 131, No. 2, February 1, 2005.

Geogrid Reinforce Embankments/Technology





Construction Method

1. Determine reinforcement requirements
2. Order material
3. Excavate jobsite
4. Excavate the base trench
5. Install base material
6. Install base course
7. Install drainage material
8. Backfill and compact soil behind the wall
9. Install second course
10. Install geogrid
11. Install additional courses
12. Ending and topping of walls

Application

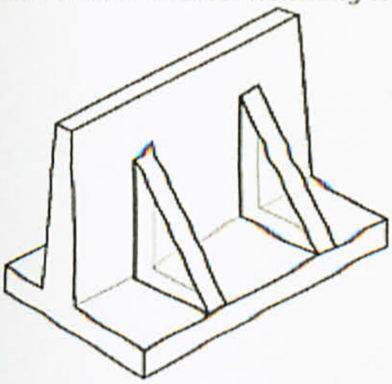
1. Toe protection for shallow landslide
2. Retaining wall
3. Deep seated landslide prevention

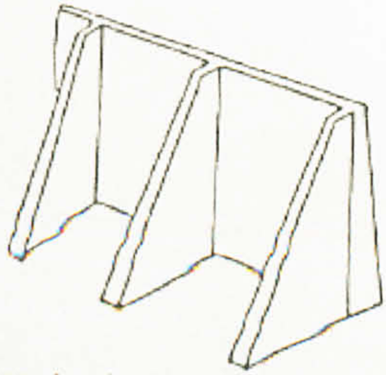
Reference

1. Allan Block Corporation . 1998 <www.airvolblock.com>.
2. F. Tatsuoka, M. Tateyama, Y. Mohri and K. Matsushima, " Remedial treatment of soil structures using geosynthetic- reinforced technology", Geotextiles and Geomembranes 25(2007) 204-220.
3. Rogers, J. D. , 1992. Recent developments in landslide mitigation techniques. In Slosson, J.E., Keene, A.G. and Johnson, J.A., eds., Landslides/ Landslide Mitigation: Boulder, Colorado, Geological Society of America Reviews in Engineering Geology, Volume IX, p. 95-118.
4. M. I. M Pinto, "Applications of geosynthetics for soil reinforcement ", Ground Improvement (2003) 7, No 2, 61-72, January 13 2003.
5. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.

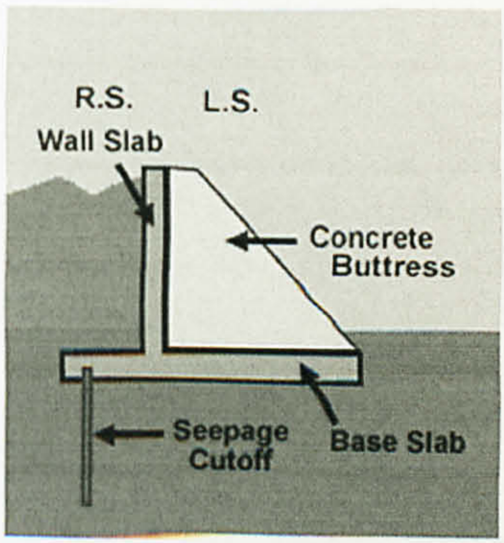
Buttress Counter-forts (Coarse grain Material)

Counterfort or Buttress Retaining Wall





concrete buttress wall
or braced wall



Buttress Wall

Note: R.S. = River Side (or seaward, unprotected side)
L.S. = Land Side (or protected side)

Construction Method

1. The foundation of the wall is first constructed by using piling for shear key reason and etc.
2. The wall is then constructed based on the height of the design
3. Drainage material and drainage structure are the installed concurrently before the compaction takes place

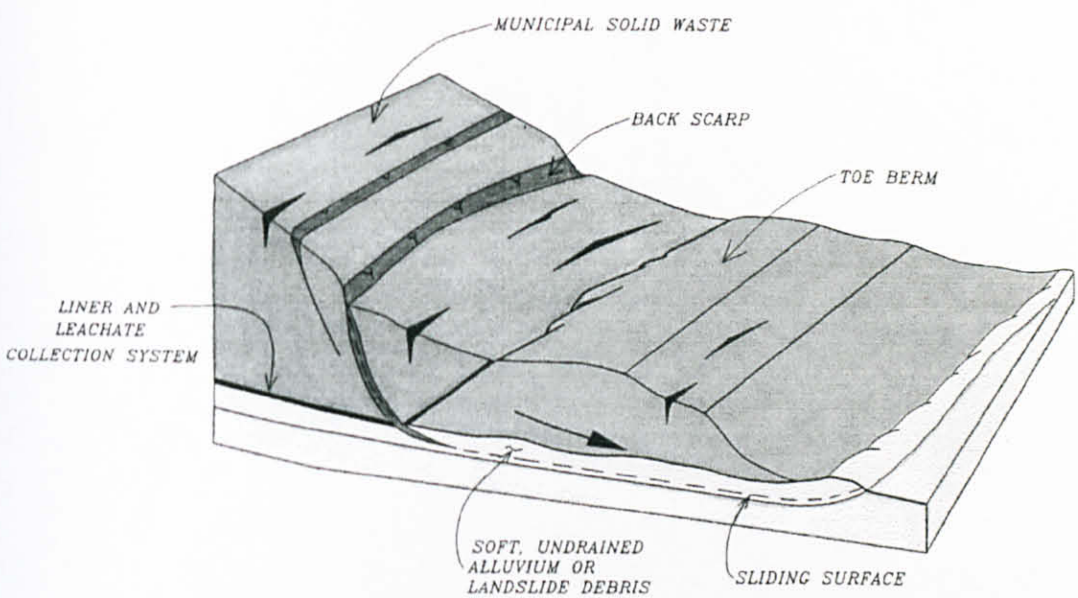
Application

1. Mitigation for earth and debris topple
2. Toe protection for slides (translational/ horizontal)
3. Mitigation for spreads failure
4. Toe protection for complex landslide failure

Reference

1. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.
2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
3. Rogers, J. D. , 1992. Recent developments in landslide mitigation techniques. In Slosson, J.E., Keene, A.G. and Johnson, J.A., eds., Landslides/ Landslide Mitigation: Boulder, Colorado, Geological Society of America Reviews in Engineering Geology, Volume IX, p. 95-118.

Toe berm



SCHEMATIC OF TOE BERM AND LANDFILL SLIDING ALONG WEAK FOUNDATION LAYER

Construction Method

1. Mobilization of equipment
2. Site preparation
3. Deposition of embankment material
4. Compaction
5. Subgrade treatment

Application

1. Protection at the toe for deep seated landslide

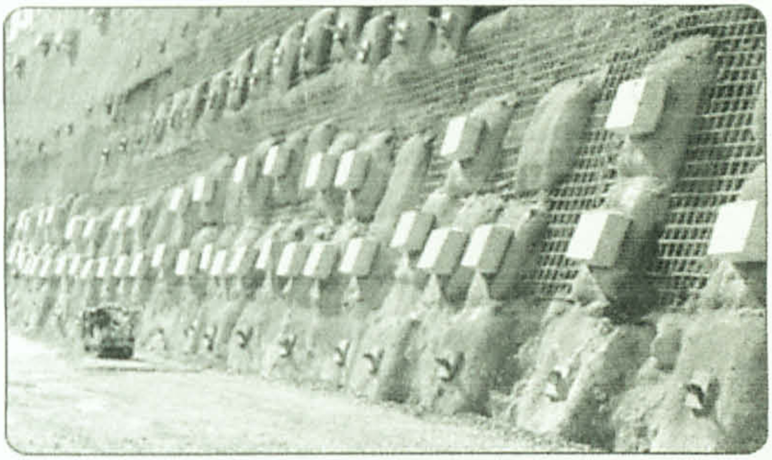
References

1. 2009 <http://www.iowadot.gov/erl/current/CM/content/6-40.pdf>.

2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.

INTERNAL SLOPE REINFORCEMENT

Rock anchors



Construction Method

1. Select a site for each anchor where the best quality rock is available. Try to avoid deeply weathered or intensely jointed or broken rock. The anchor should be embedded in the rock for the entire length and any length needed for connectors should be added. The rock strength selected for design should extend a distance at least equal to the anchor length in all directions from the anchor location. Care should be taken here, because the lateral extent of the rock may be masked by overburden soils. Rock depth will be determined when the hole for the anchor is drilled.

2. Drill the smallest size hole in the rock that will accept the anchor bar. The axis of the hole must align with the direction of the cable guy to be anchored.

3. Grout the anchor bar in the hole in accordance with the grout manufacturer's recommendations.

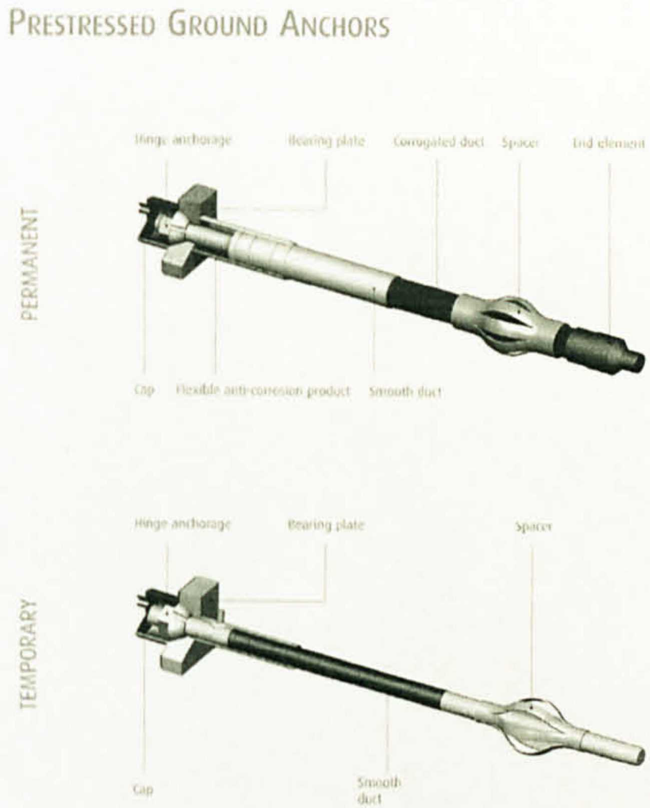
Application

1. Rock slide mitigation
2. Earth slide mitigation (topple, complex, spread, rotational and translational)

Reference

1. W.L. Schroeder and D.N. Swanston. April 1992. "Installation and Use of Epoxy-Grouted Rock Anchors for Skyline Logging in - Southeast Alaska", PNW-GTR-297, United States Department of Agriculture
2. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.
3. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
4. AD HOC COMMITTEE of the PCI POST-TENSIONING COMMITTEE. 15 Feb 80. Tentative Recommendation for Prestressed Rock and Soil Anchors. EM 1110-1-2907, < http://140.194.76.129/publications/eng-manuals/em1110-1-2907/a-e.pdf>.

Pre-stressed ground anchors



Construction Method

1. Drilling
2. Tendon manufacture and installation
3. Grouting
4. Stressing

Application

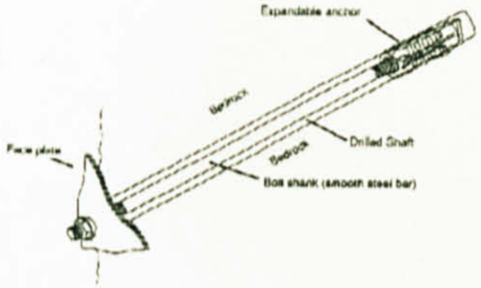
1. Rock fall prone areas/ Hilly terrain with highly eroded rock

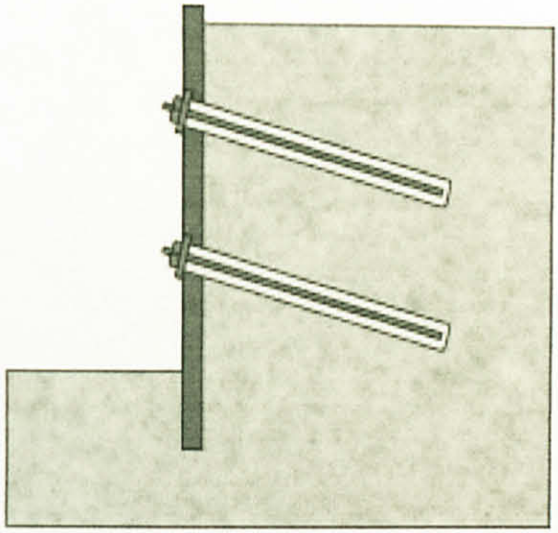
Reference

1. P A Wymer, R A Robinson, D T Sharp, "Ground Anchor Practice in New Zealand - A Review of Applications, Design and Execution" "<http://www.contech.co.nz/uploaded/A%20Review%20of%20Ground%20Anchor%20Practice%20in%20New%20Zealand%20-%20March%20_.pdf>.
2. AD HOC COMMITTEE of the PCI POST-TENSIONING COMMITTEE. 15 Feb 80. Tentative Recommendation for Prestressed Rock and Soil Anchors. EM 1110-1-2907, < http://140.194.76.129/publications/eng-manuals/em1110-1-2907/a-e.pdf>.
3. J Suguwara, "Soil Nailing Technology and Japanese Landslide Mitigation Works", Geo-Singapore 2006 : An International Conference on Geotechnical Engineering, 11-13 December 2006, Singapore

Rock bolts

FIGURE 5: TYPICAL ROCK BOLT





Construction Method

1. The hole is drilled using drilling equipment until the targeted depth
2. The nail is then stressed out by using tightening method to expand the anchor at the end of the nail

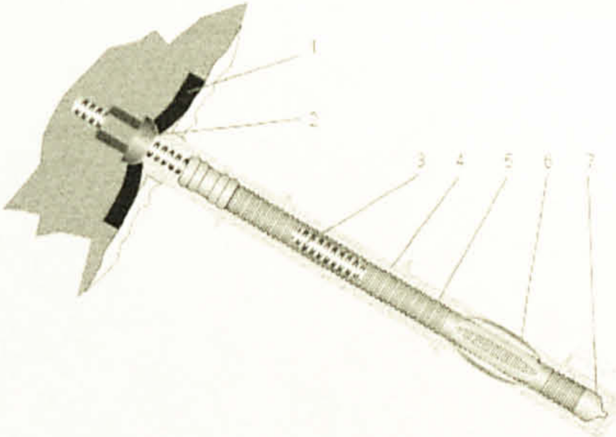
Application

1. Rockfall mitigation measures.
2. Rockfall mitigation for road or bridge construction for embankment purposes.

Reference

1. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
2. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.

Soil nails



Construction Method

A bench is excavated ranging between 4 and 6 feet in height. Holes are drilled into the excavated face typically measuring 6 to 8 inches in diameter in soil and 3 to 4 inches in rock. Typically, holes are angled at 15 degrees below horizontal.

The hole is pumped full of ready-mixed grout soon after drilling to ensure the hole remains open. Nails, generally continuously threaded steel bars, are long enough to penetrate the failure plane of the excavation, and are inserted immediately following grouting. The nails are equipped with centralizers to ensure central placement in the grouted hole.

The concept is to stabilize the soil by creating a grouted mass that the surrounding soil will act upon in friction. The grout also provides corrosion protection for the nail. Once the grout sets, the protruding nails are fitted with a steel plate to transfer forces from the wall to the nail.

Horizontal and vertical drain strips are then installed onto the facing to control seepage and eliminate hydrostatic pressure buildup. Reinforcing steel is applied and the face is shotcreted. For temporary walls, as in shoring or behind a cast-in-place concrete finish, the surface can be left rough or lightly troweled.

For permanent walls, the shotcrete can be hand troweled or even sculptured and stained to blend into the natural surroundings depending on the desired look. Because of the potential that the soil will collapse after being excavated, a soil nailing contractor only cuts as long a bench as crews can complete in a 24- hour period.

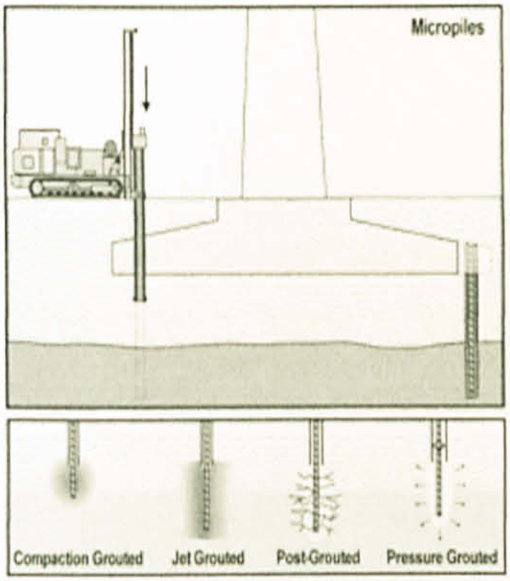
Application

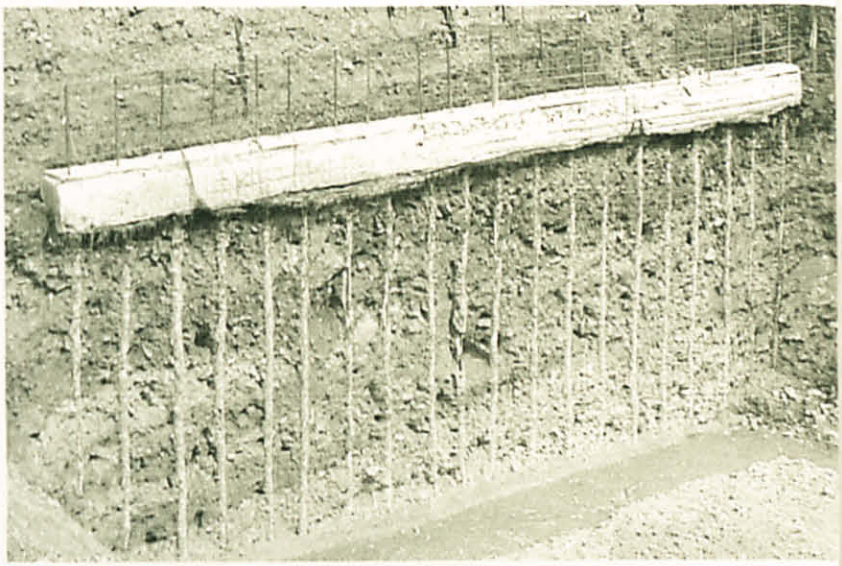
1. For embankment construction
2. For soil reinforcement purposes

Reference

1. Sara McGray. July 2003 <http://www.judycompany.com/engineer/articles/betterroads-0309.pdf>
2. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.
3. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
4. John. P. Turner and Wayne G. Jensen, " Landslide Stabilization Using Soil nail wall and mechanical stabilized earth walls", Journal of Geotechnical and Geonvironmental Engineering, Vol. 131, No. 2, February 1, 2005.

Micro-pile





Construction Method

1. The pile point is determined by a surveyor and position the drill rig on top of the top
   The first drill rod with a drill bit is placed above the drill point
   Ensure the verticality is achieved before starting the drill works
   This is done by checking the verticality of both the first drill rod and the mast using a spirit level

2. For drilling in soft and/or hard soils (typically SPT N>5), the hole can be drilled with the wash boring method either using a drag bit or roller (tricone bit)

   Wash boring, also known as the reverse circulation system is an assembly of the drill bit-drill bit or drag bit or roller bit being assembled to the end of a string of drill rods onto a drill rig or a drill frame. The drill bit is advanced by adding drill rods when drilling. Water is pumped through the string of drill rods and the outflow water emerging from the borehole is channeled to a holding pit and recycle to a slurry pump back into the drill rig's swivel head – hence the terms 'reverse circulation'.

3. If collapsible layers is encountered from step 2, or anticipated form the soil investigation record, drilling using temporary casing shall be employed.

   Advance a casing into by either drilling using a casing shoe (by wash boring method) without the aid of a drill rod OR using a drill rod with drag/roller bit together with a casing up to the suspected collapsible layer felt by the driller or SI report. The latter report can be done without a casing shoe.
   Upon reaching the end of the collapsible area (usually sand), cease the advancing of the casing. Continue drilling using drag/roller until the depth of the pile is reached.

4. Upon completion of the drilling, the borehole is cleaned by flushing out any soil particle from inside of the casing with recirculation water or air

   API pipes/ Reinforcement Bars (Cage installation) :-

   If a mobile crane is to be used for, move the drilling rig back. The pipe/ rebar cage shall be lowered segment by segment using a mobile crane. Cordon the area for safety reasons. If the drilling winch is to be used, lift the bar/cage up segment-by segment using the winch. Cordon the area for safety reasons

   The joint of the API pipe shall be properly screwed together with grease to assist tightening. If welding is used, clean the edge of the pipe and conduct a full butt weld on the outside of the pipe. If reinforcement bars are used, lap the bar for 40D and join by tie wire or welding.

5. In step 4, the mobile crane is used to install the API pipe/rebar cage, the same mobile crane can be used to pull/withdraw the temporary casing.

   Shall this cannot be done due to safety reasons(crane parked too far away), move the drill rig back. Withdraw the casing using winch tied around the casing. Shall this be unsuccessful, reattach the adapter and using the reverse circulation method(wash boring), flush water into the casing to loosen it while withdrawing the casing using the rotary unit.

6. Mix the cement bag with water in a mixer according to the design mix measurement. The mix grout shall be filtered and poured into a holding tank.

   Grouting of the micropile is the carried out by Tremie method using a hose installed right up to the end tip of the pile Rebar assembly cage or API pipes with flow holes cut at the tip of the API pipe. Pump the grout into the pile using a piston or diaphragm pump. Grouting is done until neat grout appears at the top of the borehole. Upon completion, the grout hose is extracted.

   Shall any leftover temporary casing is extracted, or at any time after grouting, the grout level drops below the cut-off level, top-up the hole with grout.

Application

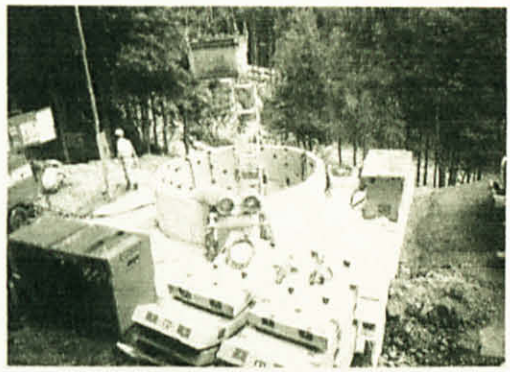
1. Retaining wall foundation for weak soil strata
2. For housing foundation

References

1. Method Statement for Installation of Micropile <http://geoprofound.com/download/mst-all.pdf>.
2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
3. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.

DRAINAGE

Drainage well and tunnels

Construction method

1. Well are augered using auger machinery and the placement of the concrete wall is done concurrently to prevent collapse of the soil wall.
2. Concrete wall are lowered down piece by piece and the concrete are pre-cast.
3. Workers then apply sealant material such as grouting or etc to provide cohesiveness and watertight sealant between the joints of each pre-cast concrete wall.

Application/Place

1. For water collection in reducing water table for landslides

Reference

1. E . N . Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997

2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.

Slit Dam/ Earth Dam

Construction Method

1. Earthwork is implemented first such as piling, cut and fill etc to fit the design dimension of the dam
2. Concreting work is then proceed

Application

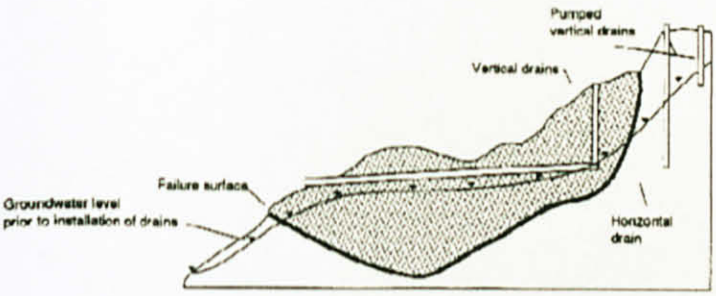
1. For debris and earth flow landslide situation
2. Suitable for flood retention structure

References

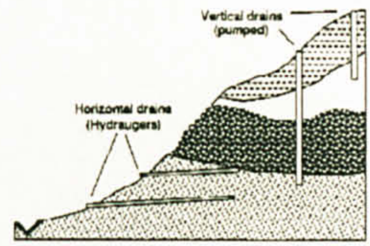
1. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
2. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.
3. Peggy A. Johnson and Richard H. McCuen, "Slit dam design for debris flow mititgation", Journal of Hydraulic Engineering, Vol 115, No. 9, 1293-1296, September, 1989.

Horizontal drain

FIGURE 3: HORIZONTAL AND VERTICAL DRAINS INSTALLED FOR SURSURFACE DRAINAGE CONTROL (modified after Gedney adn Heber, 1978)



B. Stabilization of landslide by dewatering; generally used in conjunction with other methods of stabilization



A. Horizontal and vertical drains to lower groundwater in natural slope

Construction Method

1. The groundwater is identified first
2. Temporary well is constructed to intercept the groundwater flow to avoid any problem during the construction
3. Hole is drilled using the driller to reach at the targeted depth
4. Pipe is then installed

Application

1. Drainage at the toe of the deep seated and shallow landslide
2. For rockfall drainage purposes

Reference

1. The Japan Landslide Society. <http://www.tuat.ac.jp/~sabo/lj/ljap4.htm>.
2. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.
3. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.

4. Rogers, J.D., 1992. Recent developments in landslide mitigation techniques. In Slosson, J.E., Keene, A.G. and Johnson, J.A., eds., Landslides/ Landslide Mitigation: Boulder, Colorado, Geological Society of America Reviews in Engineering Geology, Volume IX, p. 95-118.
5. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.

Surface Drainage

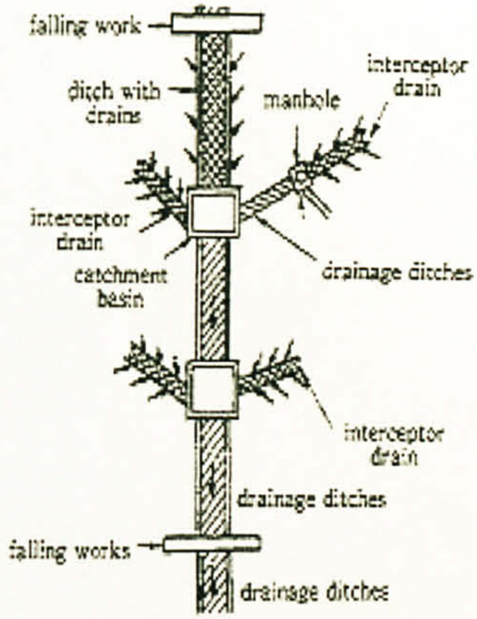


Fig. 35 Arrangement of ditches and interceptor drains

Construction Method

1. Drain are excavated by the given dimension using men or mechanical machinery
2. Concreting work are proceed to develop the necessary structure/ element for the surface drainage
3. Finishing is done to ensure quality of the workmanship.

Application

1. Surface drain for deep seated landslide (earth and debris material)
2. Surface drain for shallow landslides (earth and debris material

Reference

1. The Japan Landslide Society. <http://www.tuat.ac.jp/~sabo/lj/ljap4.htm>.

2. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.
3. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.
4. Rogers, J.D., 1992. Recent developments in landslide mitigation techniques. In Slosson, J.E., Keene, A.G. and Johnson, J.A., eds., Landslides/ Landslide Mitigation: Boulder, Colorado, Geological Society of America Reviews in Engineering Geology, Volume IX, p. 95-118.
5. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEAN SX005554AWD04D04TT2.pdf>.

Shallow trench drain

Construction Method

1. The drains are excavated by mechanical machine to achieve its related dimension design.
2. Concreting work were done to make sure the drain are fully completed
3. Filtration pit or sedimentation pit are installed concurrently to improve the water flow during heavy rainfall

Application

1. Surface drain for deep seated landslide (earth and debris material)
2. Surface drain for shallow landslides (earth and debris material)

Reference

1. E. N. Bromhead, "The Treatment of Landslides," Proc. Isnstn Civ. Engrs Geotech. Engng, 1997, 125, Apr, 85-96, 16 June. 1997.
2. M. E. Popescu, "Landslide Causal Factor And Landslide Remediatial Options,"< http://www.geoengineer.org/Lanslides-Popescu.pdf>.

3. Rogers, J.D., 1992. Recent developments in landslide mitigation techniques. In Slosson, J.E., Keene, A.G. and Johnson, J.A., eds., Landslides/ Landslide Mitigation: Boulder, Colorado, Geological Society of America Reviews in Engineering Geology, Volume IX, p. 95-118.

Shotcrete

Method of construction

1. Build each layer by making several passes over the working area. Thickness of each layer shall be governed by the requirement that sagging of shortcrete shall not occur. Maintain top surface of thick layers at 45 degree slope. Each layer to be covered by a succeeding layer shall be allowed to take its initial set.
2. Laitance, loose material, and rebound shall be removed by air-jetting. Laitance that has taken a final set shall be removed by sandblasting and the surface cleaned with air-water jet. All layers to be shot shall be damp.

3. Unless otherwise permitted, begin application at the lowest elevation.
4. Do not trowel or finish initial layers in any way.

Application

1. For rock fall treatment in the shape of topple, falls, and spread.
2. For erosion control purposes

Reference

1. Gareth Collins, Ian Stewart , June 05. Shotcrete Design Guideline <http://www.rta.nsw.gov.au/constructionmaintenance/downloads/urbandesign/shotcrete_design_guidelines.pdf>.
2. <http://www.efka.utm.my/thesis/images/3PSM/2004/3JGP/Geoteknik1/LEEPHOIYEANSX005554AWD04D04TT2.pdf>.
3. <http://www.bart.gov/docs/std_spec/bfs/bfs_2_0_spec/stdspec/03%2037%2013.pdf>.

1.1.4 Translational slides mitigation

Translational slides failure happens at a horizontal plane. For translational rock failure, the same mitigation is adopted from rotational slides.

1.1.5 Spreads mitigation

For spreads, the failure is consist of earth and rock in a single group and earth spreads in single group. The form of this failure movement is most likely in a horizontal form.

For mitigation measures, slope adjustment, slope vegetation, piling, gabion, sheet pile, surface, horizontal, and shallow trench drain retaining wall and buttress counterforts.

1.1.6 Flows mitigation

For flows failure, rock and debris are classified in one group and earth flow is separate. Material carried consists of rock, earth and debris with high amount of water. Suitable mitigation measures are drilled piers, pipe piles, earth dam, micro pile, retention wall, toe berm, slope vegetation, surface and subsurface drainage, and geosynthethic reinforced.

Earth flow mitigation can be slit dam, earth dam, diversion channel, slope vegetation, retaining wall with anchors, drainage wall, surface and subsurface drainage, and MSE with reinforce geosynthetic

1.1.7 Complex landslide failure

Complex type of landslides may consist of two or three type of movement and material carried. For example, slump-earth flow with rock fall debris and half part translational and rotational movement kind of landslide with earth flow at toe. The remedy for this kind of landslide maybe arbitrary but it mainly consists of drainage, retention structures, internal slope reinforcement, and slope angle adjustment. Choices can be such as

1. Piles
2. Horizontal and vertical drain
3. Soil nail